Geology of Mangapanian (Late Pliocene) Strata, Wanganui Basin: Lithostratigraphy, Paleontology and Sequence Stratigraphy

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ABSTRACT

Fourteen Mangapanian and early Nukumaruan (late Pliocene) cyclothems in Wanganui Basin have been studied, stratigraphically logged and geologically mapped in thirteen sections from west to east across the basin. The Mangapanian succession contains two subgroups. The **Paparangi Subgroup** contains sparsely fossiliferous siltstone and sandstone, and extends from the base of the Mangapani Shell Conglomerate to the base of the Wilkies Shellbed. Constituent formations include the **Atene Formation, Mangaweka Mudstone, Pitangi Formation** and **Moukuku Formation.** The **Okiwa Subgroup** is cyclothemic, fossiliferous, and includes all strata between the base of the Wilkies Shellbed and the Hautawa Shellbed. Constituent formations include the **Whauteihi Formation, Whakaihuwaka Formation** and **Parikino Formation.** Formational boundaries are mainly located at the base of shellbeds. Individual sandstone, siltstone and shellbed units within formations are assigned member status.

New collections of fossil molluscs allow refinement and minor emendations to the NZ Geological Timescale for bioevents occurring at the Waipipian-Mangapanian (Wp-Wm) and Mangapanian-Nukumaruan (Wm-Wn) Stage boundaries. One significant discovery is that the FO of dextrally coiled *Globorotalia crassaformis* does not mark the Wp-Wm Stage boundary. Comparison between molluscan and formainiferal bioevents is possible in the Wanganui River section. Two rhyolitic tephra (**Eagle Hill** and **Otere**) have been numerically dated. These tephra have U-Pb SHRIMP ages of 2.85 ± 0.20 Ma and 2.71 ± 0.25 Ma, respectively. Single crystal U-Th/He dating of zircon from the Otere Tephra yields an age of 2.57 ± 0.04 Ma. These numerical ages constrain new and revised magnetostratigraphic data for several sections. The Gauss / Matuyama paleomagnetic transition and "X" event cryptochron both occur within the Mangapanian succession. Shellbeds in the succession have been correlated with $\delta^{18}O$ Stages G10-88 (2.79 Ma – 2.28 Ma), providing a numerical age range for each cyclothem within the succession.

The Mangapani Shell Conglomerate (2.79 Ma), Wilkies Shellbed (2.50 Ma) and Hautawa Shellbed (2.28 Ma) have been selected for detailed investigation, and each displays an inner-shelf to upper bathyal depositional profile. Molluscan water-depth estimates for each of these units indicate that they are transgressive deposits, and together with their overlying siltstone and sandstone units comprise a 41 k.y. sequence. Similarities in the character of these three sequences provide constraints upon which a model cyclothem is based. Comparison of other 41 k.y. sequences within the Mangapanian succession with the model cyclothem reveal subtle patterns in sequence architecture, from which predictions of paleoshelf position can be made for particular sections / logs. While most sequences exhibit a consistent westward shallowing trend, many sequences appear to exhibit expression of their shallowest parts in the central parts of the basin, with increases in water depth both eastward and westward of this point. The point of inferred closest proximity to a paleoshoreline for outcrop sections is named Point "S". Tracing the locality of Point "S" for successive sequences reveals that it occurs in the central parts of the basin during the late Mangapanian. This pattern is correlated with the transfer of strain across the deep subduction interface of the Indo-Australian and Pacific plates. Paleogeographic maps depiciting the shape of Wanganui Basin at both the beginning and end of the Mangapanian show the southward migration of the basin depocentre, and that a western basin margin probably separated the Wanganui Basin from the Tasman Sea.

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CHAPTER ONE:

INTRODUCTION.

Overview.

This study is intended to be a comprehensive investigation of the Mangapanian (late-Pliocene) sedimentary succession within Wanganui Basin. This basin is situated in the southwestern part of North Island, New Zealand. The basin contains the type areas for several New Zealand Pliocene and Pleistocene geological stages, of which one, the Mangapanian Stage, is the subject of this thesis. Strata of this age accumulated mainly in shallow marine (shelfal) conditions, and contain a wide variety of facies. The Mangapanian Stage itself is a biozone, which is defined by multiple molluscan bioevents that separate it from other stages in the basin succession.

Since C. A. Fleming published his bulletin "The Geology of Wanganui Subdivision" in 1953, little attention has been paid to the Mangapanian succession in the basin. While that study advanced geological understanding of the region considerably, most of the strata within the Mangapanian Stage remained undifferentiated. A major part of this thesis study has been to comprehensively describe the lithostratigraphy within this interval and map the many units within it.

The emergence of sequence stratigraphy in the late 1970's (Payton, 1977) as a way of classifying recurrent marine sedimentary deposits and linking them to sea-level changes revolutionised the study of cyclothemic successions. This followed soon after the discovery of evidence for repeated 100 k.y. and 41 k.y. sea-level oscillations during the Plio-Pleistocene in the form of ^{18}O / ^{16}O curves derived from the foraminifera recovered from deep-sea cores that had been dated paleomagnetically (Shackleton & Opdyke, 1973; 1976; Shackleton *et al.,* 1995). Thus it is expected that the shallow-marine deposits of Mangapanian age in Wanganui Basin should contain evidence for cyclic sea-level changes. Prior to this study Abbott & Carter (1994) and Naish & Kamp (1995; 1997) had reported sequence stratigraphic interpretations for Nukumaruan and Castlecliffian (latest Pliocene and Pleistocene) successions in the basin, the origin of which they attributed to glacio-eustatic sea-level oscillations.

Despite the region being the type area for the Mangapanian Stage, details of stratigraphic relations between the original molluscan bioevents and more recently identified foraminiferal bioevents, located in more eastern, deeper water parts of the basin (McGuire, 1989; Journeaux, 1996; Hayton, 1998) were not well understood. Particular emphasis is placed in this study on correlation of the molluscan bioevents from more western sections into the deeper water sections that have an existing foraminiferal biostratigraphy. Considerable effort has also been placed on establishing a numerical chronology for the succession, based on magnetostratigraphy and radiometric age determinations of tephra.

Previous studies involving Mangapanian strata in the eastern part of Wanganui Basin (Journeaux *et al.,* 1996) revealed that most strata of this age accumulated in outer-shelf to upper bathyal water depths. McIntyre & Kamp (1998) investigated correlative strata in the central part of Wanganui Basin, and reported a variably inner to mid shelf cyclothemic succession. A rationale for this study was to establish the transition between these widely separated areas with constrasting facies and sequence expression. An opportunity seemed to be present to map deposits across a paleoshelf and into an upper bathyal succession (Mangaweka Mudstone).

Outline of the study.

The relative isolation of much of the region investigated in this study may have contributed to the paucity of previous investigations. While Fleming (1953) described parts of the succession, the majority of Mangapanian strata remained undifferentiated. This necessitated a substantial amount of fieldwork, and approximately a year was spent in the field establishing a lithostratigraphic framework for all strata of this age in Wanganui Basin. This involved describing and mapping units across the basin, and constructing stratigraphic columns for each section. The columns are presented in Enclosure 1. To assist with differentiation between units, textural samples were taken at ~ 2 m stratigraphic intervals in the main sections in the expectation that they would reveal repetitive grainsize alternations. Particular emphasis was placed on the collection of fossil molluscs, for both biostratigraphic and paleoenvironmental purposes. These have been archived in the University of Waikato fossil collection, and the faunal lists are presented in Appendix 2. The areas that have been mapped are summarised in Figure 1.1, which show the relative positions between the 1 : 40,000 scale geological maps figured in Enclosure 2.

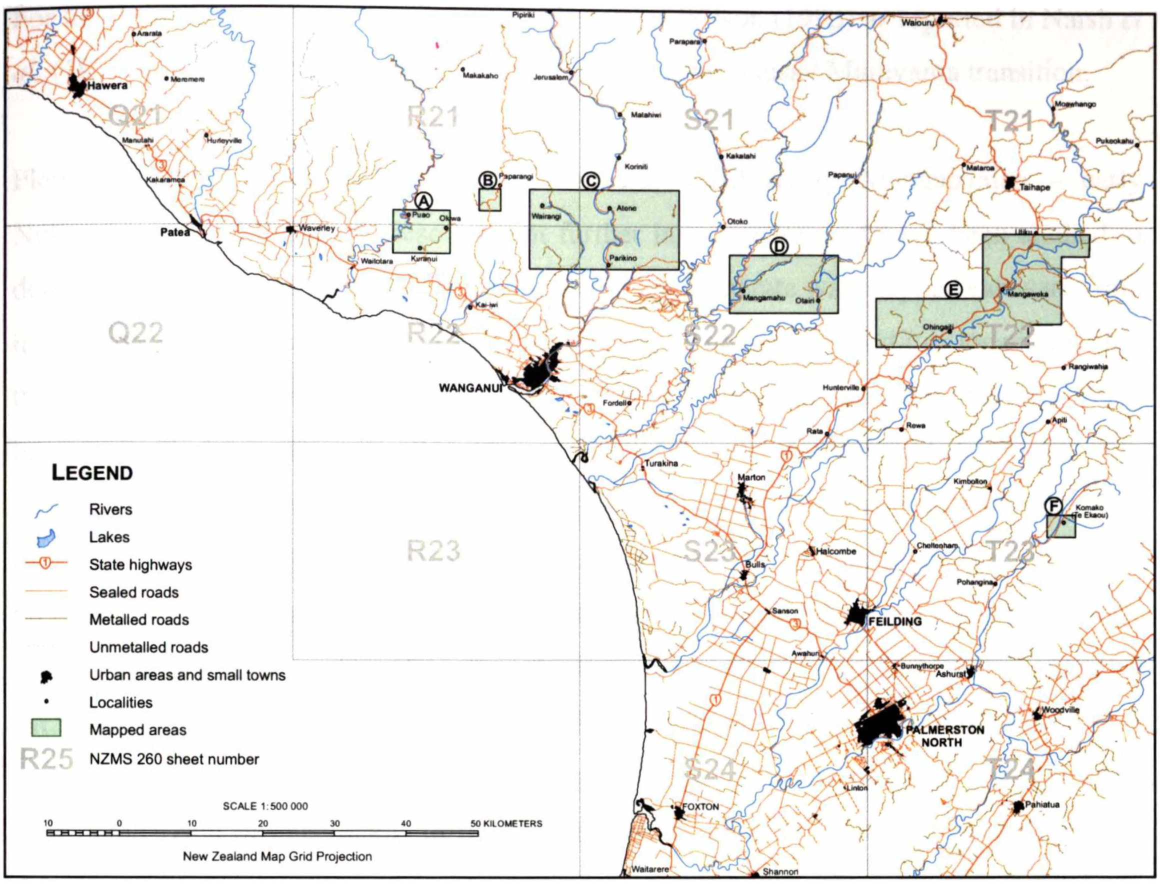

Figure 1.1: Position of areas geologically mapped with the Wanganui region. The maps are presented in Enclosure 2.

Correlation of strata between the 13 sections investigated in this study was assisted by the distinctive character of units, in particular the Mangapani Shell Conglomerate and the Hautawa Shellbed. These units can be correlated with confidence because of the molluscan bioevents associated with each of them.

The fossil collections made in this study supplement those of earlier workers (i.e. Laws, 1940; Fleming, 1953; Carter, 1972) and where possible, these existing fossil lists have been updated and integrated with this study to increase the biostratigraphic resolution of the succession. Correlation of strata between the various sections has facilitated the integration of molluscan and foraminiferal biostratigraphy for this part of the Pliocene succession. To provide a numerical chronology to the succession, the magnetostratigraphy was established for several sections. This was intergrated with the Geomagnetic Polaity Time Scale (GPTS) by the results of U-Pb SHRIMP and U-Th/He radiometric age determinations of juvenile zircons from two tephra (Eagle Hill and Otere Tephras).

For the Rangitikei section, the paleomagnetic data of Wilson (1993) as reported in Naish *et al.* (1996) was re-evaluated to confirm the position of the Gauss / Matuyama transition.

Fleming (1953) identified and described several shellbeds of Mangapanian – early Nukumaruan age. Three of these warrant further investigation and have been studied in detail as part of this study. The Mangapani Shell Conglomerate was mapped eastward from its type locality into the Wanganui River section, as its occurrence and / or location within this section for which there is a foraminiferal biostratigraphy (Collen, 1972; Hayton, 1998) has previously been unknown. The Wilkies Shellbed contains a unique fossil fauna, with large thicknesses of *Crassostrea*. Close investigation of this unit was necessary to explain its character. The Hautawa Shellbed features relatively commonly in the geological literature, but published details of relations between this unit and the Kuranui Limestone are vague. Further investigation of each of these units has shown that each unit is part of a cyclothem. The common features of each of these cyclothems form the basis of a model cyclothem, to which other cyclothems in the Mangapanian succession can be compared. This comparison reveals details of the stratigraphic and sedimentological development of the Wanganui Basin fill, which in addition to the marked effect of global sea-level oscillations, may contain a subtle record of tectonic movements driven by the dynamics of interaction across the subduction zone plate interface.

Summary of objectives.

The principal objectives of the thesis include the following:

- Describe all strata of Mangapanian age in multiple sections within the basin.
- Map and correlate units across the basin.
- Re-evaluate the molluscan biostratigraphy associated with the Stage, and relate the molluscan biostratigraphy to the existing foraminiferal biostratigraphy.
- Provide a numerical chronology for the Stage, and match cyclothems with the global Oxygen Isotope Stages.
- Examine the Mangapani Shell Conglomerate, Wilkies Shellbed and Hautawa Shellbeds in detail, and interpret them in terms of sequence stratigraphy.
- Develop a sequence stratigraphic model showing the distribution of systems tracts across the paleoshelf.
- Apply the model cyclothem to the cyclothems in the Mangapanian succession that were not used to develop the model, to help in establishment of the elements of the paleogeography.
- Assess the implications of this study in terms of the development of Wanganui Basin for this interval.
- Interpret the overall development of Wanganui Basin during the Mangapanian Stage.

CHAPTER TWO:

GEOLOGICAL SETTING AND PHYSIOGRAPHY.

Introduction.

Situated in the south-western part of North Island, the Wanganui Basin is a major Cenozoic sedimentary basin. The basin is located behind the forearc part of the Indo-Australian / Pacific plate boundary, and its occurrence is considered to result from sublithospheric tectonic loading, accentuated by sediment loading, driven by intermittent coupling of the overlying (Indo-Australian) and underthrusting (Pacific) plates (Stern *et al.,* 1993) (Figure 2.1). The dextrally oblique nature of the interaction between the two plates has resulted in the generally southwards migration of the Wanganui Basin depocentre from the vicinity of the central-western North Island in the late Miocene – early Pliocene to its present position north of Cook Strait. This has resulted in the accumulation and subsequent uplift of a gently southward-dipping (2-15°) c. 5 km thick succession of mainly shelfal sediments, which progressively offlap older strata from the north, and onlap basement to the south. The Ruahine and Tararua Ranges form the modern eastern margin of the basin. In the west, the Patea-Tongaporutu High, bounded on the west by the Taranaki Fault, separates the Taranaki and Wanganui Basins. The Marlborough Sounds mark the southern basin margin (Figure 2.2). To the north, the strata become successively older, with the oldest being Oligocene in age, in the Te Kuiti region. The basin fill is comprised of a near-complete sedimentary record spanning from the late Oligocene to present, comprised mainly of shallow marine to bathyal deposits. The southward migration of the basin depocentre has been accompanied by uplift in the northern parts of the basin, which has resulted in the exposure of much of the basin fill on land.

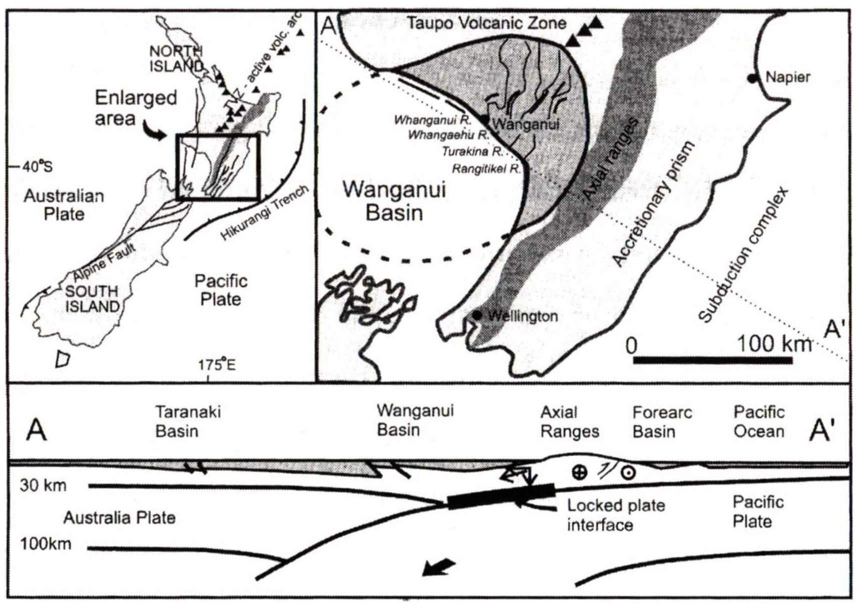

Figure 2.1: A schematic cross-section across Wanganui Basin showing its regional tectonic setting with respect to the main structural features of the Hikurangi margin. (after Carter & Naish, 1998)

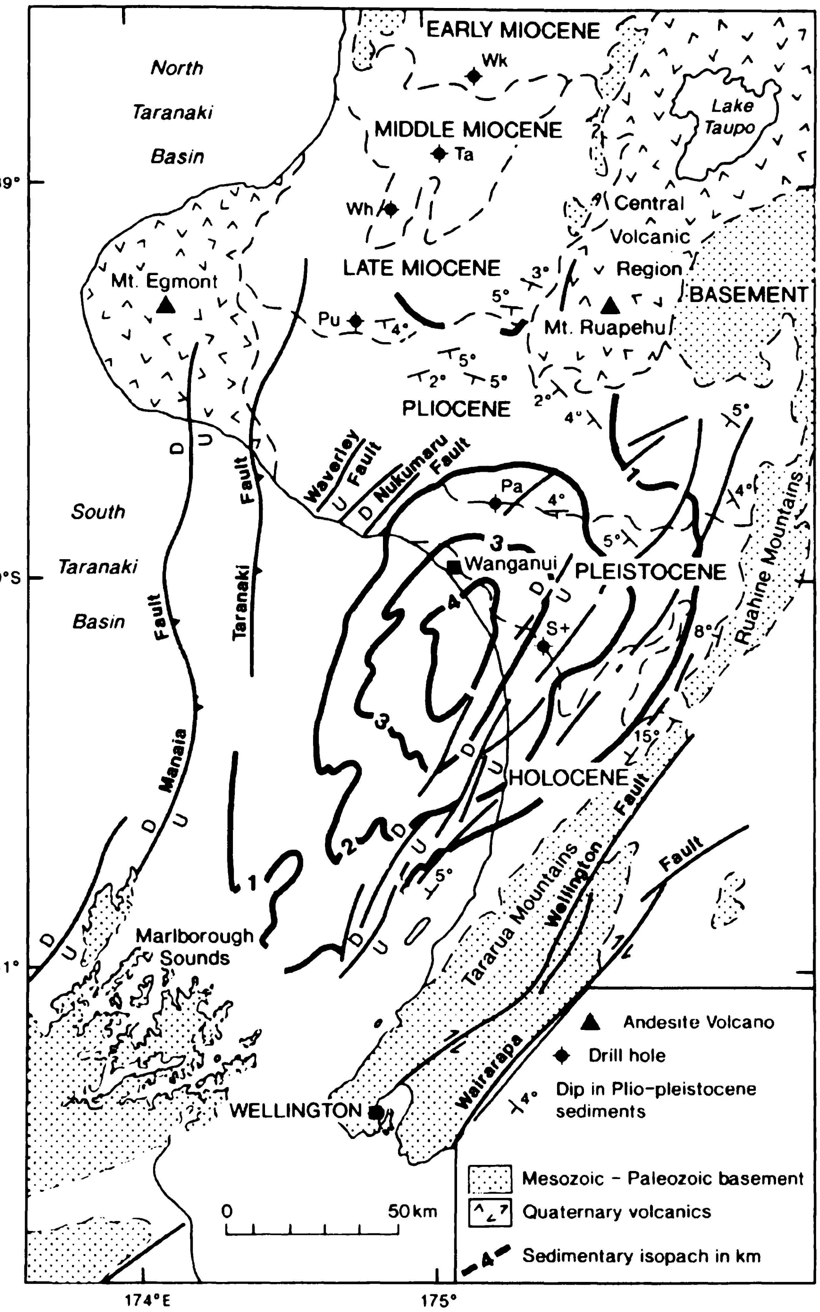

Figure 2.2: Key features of Wanganui Basin including basin margins, simplified geology and thickness of Cenozoic cover beds. (after Stern *et al.*, 1993)

Basin fill.

The basin fill accumulated during an interval of Earth's history for which known glacio-eustatic sea-level fluctuations occurred (e.g. Shackleton *et al.,* 1995). The sedimentation in the basin was dominated by accumulation in shelf paleoenvironments that reflect a sedimentary response to global galcio-eustacy (Beu & Edwards, 1984; Kamp & Turner, 1990; Abbott & Carter, 1994; Naish & Kamp, 1995). The imprint of the global sea-level signal accounts for the repetitive occurrence in Castlecliffian and Nukumaruan successions of shellbeds, siltstone and sandstone beds. In the central parts of the basin, thick (several hundred metres) massive siltstones of Mangapanian and Waipipian age are common, and accumulated under upper bathyl conditions (MacGuire, 1989; Journeaux, 1996; Kamp *et al.,* 1998). Siltstone comprises the most common lithology within the basin (~ 60 % by thickness), followed by sandstone (~ 40 %) and shellbeds / limestone (~ 1-2 %). The occurrence of fossil shell material (chiefly molluscan) within shellbeds of regional extent facilitates biostratigraphic subdivision of the shelfal strata within the basin, and paleontological studies in the early – mid 20th century (e.g. Hutton, 1873; Marshall & Murdoch, 1920, Fleming, 1953) led to the establishment and subdivision of the NZ Geological timescale for much of the Plio-Pleistocene in Wanganui Basin. Several biostratigraphic Stages were created, including the Waipipian, Mangapanian, Nukumaruan, Castlecliffian and Haweran Stages, all of which have their type sections in western Wanganui Basin (Beu, 2001).

The Mangapanian succession.

The strata representing the Mangapanian Stage are the focus of this study, and have a late Pliocene age. This interval is contains 13 sedimentary sequences, which appear to have a periodicity of approximately 41 k.y. Strata of this age crop out in a belt oriented east-west across the basin with a strike of ~ 110°, and dip consistently at 4-5° to the south. The succession contains shoreface-inner shelf strata in the west to the north and north-west of

Wanganui City. They pass into slope - upper bathyal strata in the vicinity of Mangaweka and Ohingaiti in the eastern part of the basin. This eastward-deepening trend provides a unique opportunity to trace sequences in profile across a paleoshelf and examine their architecture in detail. The various shellbeds within the succession provide a useful means of tracing correlative units between sections, to the point where distinctive facies lose their lithological character and pass into deeper-water siltstone to the east. The sequences within the Mangapanian Stage have a common general motif. A lower shellbed (usually about 1 m thick) can have either a conformable or an unconformable base. The central member of most cyclothems is a siltstone bed, 10-30 m thick, which conformably overlies the shellbed. The uppermost member of most is a sandstone bed, 5-20 m thick, which conformably overlies the siltstone bed, and in most sections is overlain unconformably by the base of a shellbed at the base of the succeeding cyclothem. While containing a record of relatively high-order sea-level fluctuations (6th order), the Mangapanian succession exhibits a generally upsection shoaling. Much of the early Mangapanain sediment is slope-bathyal siltstone facies, which coarsens upward, reflecting the shelf progradation of a paleoshelf across the basin at the end of Mangapanain time. As the succession is generally hinged to a western paleoshoreline, the development of this shelf across the basin provides a unique opportunity to examine the architecture of sedimentary sequences in a shore-normal section.

Faults.

At the surface, the Wanganui Basin fill is weakly deformed, with a few northeast-southwest trending reverse and normal faults. In western Wanganui Basin, the Nukumaru Fault Zone is a series of small reverse faults dipping to the southeast at angles between 30 and 70 degrees (Fleming, 1953). The fault traces run generally parallel for about 30 km inland from the coast near the Waitotara River mouth. This fault zone displaces the Kuranui Limestone and strata of mid-late Mangapanian age downwards to the southeast in both the Okiwa and Paparangi sections. The fault zone is associated with a major change in the strike of the Pliocene succession from ~ 110° to the east of the fault zone, to a strike of ~

055° on the western side of the fault zone. The total throw on the fault zone is about 100 m, and its width is between 500-1000 m. The Upokongaro Fault is a normal fault that displaces the Pliocene succession between the Parihauhau and Whangaehu River valley sections. The amount of throw on the fault is difficult to determine, but appears to be less than 10 m. A new normal fault was noted during mapping in the Whangaehu River valley a few kilometres north of Mangamahu township, and is downthrown to the southeast by about 8 m. This fault strikes northeast-southwest at 034°, dipping at 54° to the southeast, displacing the Wilkies Shellbed. In the Rangitkiei River valley, the Rangitikei and Rauoterangi Faults have reverse displacement, and are upthrown to the west. The Rangitikei Fault has a throw of about 100 m, and the Rauoterangi Fault has a displacement of about 200 m (Naish & Kamp, 1995). In the Pohangina valley, the Pohangina Monocline is considered to be the surface expression of a high-angle reverse fault at depth, which has upthrown and overthrust the eastern block relative to the western one. Seismic traces reveal significant reverse faulting at depth within the basin, with most of these faults displacing both basement and cover beds. These faults occur in a series of northeast-southwest trending antiforms and synforms, which occur mainly in the eastern parts of the basin. Most of the faults observed in seismic section do not break the surface. The subsurface structure appears to have formed in response to crustal shortening. This is attributed to subduction processes focused to the east in the Hikurangi Margin. The Ruahine Range is a reverse fault-bounded basement block that separates the Wanganui and East Coast Basins, and probably only became emergent during early Nukumaruan time (Fleming, 1953; p. 296). Thus, it follows that the Wanganui and East Coast Basins were part of the same entity during the early and mid-Pliocene.

Physiography.

The soft sediments that comprise the Plio-Pleistocene basin fill are represented by two distinctive landscapes in Wanganui Basin. The northern parts of the basin are deeply dissected, with generally southward flowing rivers and streams cutting deeply into narrow, elongate valleys. Exposure is good in riverbanks and valley walls within this incised landscape, and the southward dip of the strata mean that progressively older strata are to the north up these valleys. The southen parts of Wanganui Basin are more physiographically subdued, with marine and river terraces rising in stepwise fashion inland until passing into the highly dissected hill country mentioned above. The soft nature of the sedimentary rocks means that dip-slopes are rare and not well developed, but the Kuranui and Nukumaru Limestones do form reasonably well-defined dip-slopes, which rise gently inland at an angle of ~ 4-5°. The limestone dip-slopes are partially covered by marine terraces, and also have the effect of forming a resistant cap to the underlying soft siltstone and sandstone beds. This means that the transition from flat-lying, rising stepped terraces to the highly dissected upland landscape can be dramatic. This occurs at both Okiwa and Paparangi. The lithological sections examined in this study each have a unique physiography, some of which are described below. The position of key sections within the Wanganui Basin Mangapanian succession are shown on figure 2.3.

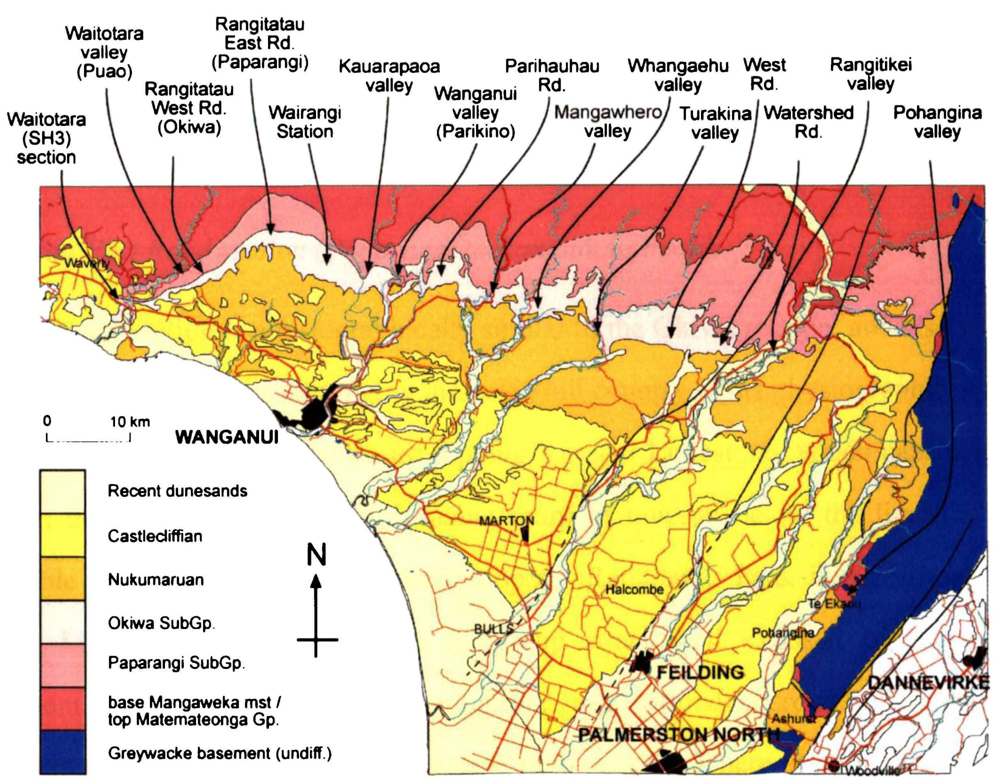

Figure 2.3: Plio-Pleistocene geology of Wanganui Basin, showing east-west striking outcrop belts and key sections where Mangapanian strata are exposed.

Okiwa Trig section (Rangitatau West Road):

The Okiwa section is located northwest of Wanganui City, at the transition from gently southward sloping terraces into highly dissected hill country. There, a gently southward-dipping limestone dip slope caps a steep northward-facing scarp in which the lower Okiwa Group is exposed. The Nukumaru Fault Zone cuts through the section as a 2 km wide zone of up to five *en echelon* normal faults parallel to the strike of the strata. This has resulted in a series of rising benches on the dip slope of the Kuranui Limestone, which rapidly gives way to deeply incised and highly dissected hill country in the northern parts of the section. Exposure of strata in the Paparangi Subgroup is very poor, due to extensive native vegetation, but improves upsection into the Okiwa Group, where the strata crop out in the escarpment below the Kuranui Limestone. The Kuranui Limestone caps all of the major hills in the area, and crops out almost continuously above Rangitautau West Road on the northern escarpment. The best exposure of the section occurs at Okiwa Peak, where at least 300 m of section is continously exposed in a steep narrow gully, extending upward from midway within the Paparangi Subgroup into the Kuranui Limestone.

Rangitatau East Road section (Paparangi to Rangitatau Peak):

The Paparangi section is physiographically similar to the Okiwa section, and also occurs at the transition from terraces into highly dissected hill country. This physiographic change is largely due to the generally southward dipping Kuranui Limestone, which caps peaks and ridges in the area, leaving the north-facing scarp of outcrop below the limestone more susceptible to erosion than the southern slopes. Rangitatau Peak is a resistant cap of Kuranui Limestone, with the Okiwa Subgroup strata well exposed on the northern escarpment. The Whenuakura and Paparangi Subgroup sediments crop out on hillsides and road cuttings in the more dissected landscape to the north. Where exposed, the Paparangi Subgroup strata are more weathered compared with the Okiwa Subgroup rocks, as the roadside outcrops within the Okiwa Subgroup are constantly eroding.

Kauarapaoa valley section (Wairangi to Wanganui River):

Kauarapaoa valley is a narrow valley (up to 1 km between ridge crests), situated c. 5 km west of the Wanganui River at Parikino, and directly north of Wanganui City. The valley lies west-east at Wairangi, curving round to flow directly south immediately before its confluence with the Wanganui River. The strata are exposed mainly in road cuttings, and also in banks and cliff faces above the Kauarapaoa Stream and its adjoining tributaries. Exposure is generally better in the lower parts of the valley; the Whenuakura Subgroup sediments in the northern part are not well exposed due to native and regenerating forest cover, and are generally inaccessible. The Paparangi Subgroup strata are also poorly exposed, as the Kauarapaoa stream is vertically slotted (typically about 10 - 15 m) into the valley floor, making the riverbanks inaccessible. The Paparangi Subgroup sediments are more competent than in the Wanganui River valley, and are exposed only as weathered, unvegetated patches on the crests of ridge spurs on hills south of the Kauarapaoa Stream. Exposure of the Okiwa Subgroup is good, with strata cropping out in roadside cuttings, riverbanks and hillsides above the Kauarapaoa Stream. Strata of the Mangapanian Stage are well represented in Kauarapaoa valley, including all of the Paparangi and the lower Okiwa Subgroups. The east-west aspect of the upper part of the valley means that some of the units (Wilkies and Hautawa Shellbeds) can be traced along strike for several kilometres. All units are marine, and have tabular geometries, striking approximately east-west (~ 110°) dipping to the south at about 5°.

Wanganui River Section (Between Atene and Parikino):

The Wanganui River is the largest river in the region. In the lower reaches the river has a relatively broad valley (between c. 1- 2 km wide between ridge crests), within which the river has meandered, resulting in a series of abandoned oxbows and meanders. Consequently, strata are well exposed both in the valley walls and riverbanks, with exposure improving upsection (and downstream) from the relatively incompetent Atene and Mangaweka Mudstone Formations of the Paparangi Subgroup to the slightly more resistant

Okiwa Subgroup sediments, which form large bluffs at Te Rimu and Parikino, in which the cyclothems are well exposed.

Parihauhau Road section:

Strata of the Okiwa Subgroup are well exposed in the Parihauhau Road section, which climbs northward from a narrow valley (about 1 km between ridge crests) to travel along the eastern watershed of the valley before dropping down to Parihauhau settlement, where the Paparangi Subgroup strata are poorly exposed. Most of the outcrop is situated where the road traverses the eastern watershed of the Upokonui Stream, with the uppermost part of the lower Okiwa Subgroup cropping out in riverbanks in the lower reaches of the valley. The Mangaweka Mudstone crops out in the northernmost part of the section, as a blue-grey, massive featureless mudstone. Only the very top of the Mangawkea Mudstone crops out on the roadside north of Parihauhau School. The Okiwa Subgroup formations are moderately well exposed in the Parihauhau Road section, mostly cropping out on the roadside as the road climbs up to and follows along the Upokonui - Makotuku watershed.

Whangaehu River section (Mangamahu):

The Whangaehu River valley at Mangamahu flows within a wide, terraced floodplain up to 1 km wide, bounded to the east and west by steep valley walls, in which the Paparangi and Okiwa Subgroup strata are well exposed. Outcrop of the strata occurs in a series of discrete bluffs spaced approximately at kilometre intervals beside the Whangaehu River. The cyclothems at the top of the Paparangi Subgroup and in the Okiwa Subgroup are moderately weathered, with common dissolution of carbonate material. Preservation improves upsection, with the Hautawa Shellbed Member forming a distinctive bed that can be traced almost continuously across the valley. The discontinuous nature of the outcrop necessitates correlation between the Whangaehu River valley and the Creek Road section to achieve a complete stratigraphy.

Turakina River section (Majuba to Otairi Stations):

Where the Turakina River valley intersects Mangapanian strata, it undergoes a downstream transition from a narrow, deeply incised valley, to a relatively wide, terraced floodplain about 1 km in width. The course of the river alternates between meanders and gorges within this floodplain. Strata are exposed higher on the sides of the valley in the meanders than in the gorges, where the best outcrop is found at or near river level. In the Mangaweka Mudstone, the amount of vegetated cover is greatest, with strata poorly exposed in roadside bluffs and riverbanks. Exposure improves downstream (and upsection) into the Okiwa Subgroup, where the strata are well exposed in large bluffs and gorges above the Turakina River. The Okiwa Subgroup outcrops are more weathered than the underlying Mangaweka Mudstone, with the fossils only poorly preserved in most outcrops.

Rangitikei River section (Mangaweka to Ohingaiti):

The Rangitkei River flows within a broad river valley of ~ 3 km in width, and is one of the major rivers in the southern North Island. A flighted succession of wide, elevated terraces rises above the Rangitkei River, marking successively older meander surfaces into which the river has incised deeply. This means that strata are exceptionally well exposed in the banks of the Rangitikei River, but jetboat access is nessecary to study the strata in detail. The Mangapanian succession is also exposed in the valley walls and steepland country on the eastern watershed.

CHAPTER THREE:

LITHOSTRATIGRAPHIC FRAMEWORK AND UNIT DESCRIPTIONS.

Introduction.

The objective of this chapter is to document the stratigraphy and structure of Mangapanian and early Nukumaruan strata in Wanganui Basin. This study builds on the earlier work of Feldmeyer *et al.* (1943), Fleming (1953), Ker (1973), Naish & Kamp (1995), Hayton (1998) and McIntyre & Kamp (1998), and is intended as a definitive classification and stratigraphic subdivision of the exposed strata within the late Pliocene part of the Wanganui Basin succession.

Approach to presentation of stratigraphic framework:

The standard lithostratigraphic approach has been adopted in this study involving the description, subdivision and mapping of the strata based on physical and facies characteristics. Sequence stratigraphy has emerged as an alternative paradigm in which to investigate cyclothemic strata, as described by Emery & Myers (1996), who provided the following simple definition for sequence stratigraphy: "... the subdivision of sedimentary basin fills into *genetic packages bounded by unconformities and their correlative conformities*". Moreover, they said "It is used to provide a *chronostratigraphic framework* for the correlation and mapping of sedimentary facies." This has resulted in "allostratigraphy", where an allostratigraphic unit is a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities (NACSN, 1983), and has been found to be applicable to successions of sedimentary sequences (Walker, 1992). The cyclothemic character of the Mangapanian and early Nukumaruan strata allows for concurrent lithostratigraphic, allostratigraphic and sequence stratigraphic subdivision. As stated above, in this chapter a lithostratigraphic approach primarily is taken to the subdivision and correlation of the succession, but it has been undertaken in such a way that sequences and systems tracts can easily be identified. While this approach is not recommended by Miall (1997, p. 13), a consistent relationship between facies, stratal repetitions and systems tracts can be demonstrated in this study, thus a "cyclo- and sequence stratigraphic friendly" lithostratigraphy is presented, while acknowledging the basic principles of lithostratigraphic subdivision as outlined by the North American Commission on Stratigraphic Nomenclature (NACSN). This states that "A clear distinction must be maintained between the division of a stratigraphic column into cyclothems and its division into groups, formations and members" (NACSN, 1983; p. 856). For example, in the area studied, the most mappable, prominent and sharp contacts between lithologically distinct units occur at the (usually) unconformable contact between loose sandstone and moderately cemented shellbed-limestones, where the more competent and resistant shellbeds form overhanging, sharp-based bluffs. These prominent surfaces are usually of regional extent, and thus are a logical surface for stratigraphic subdivision, with most group, subgroup and formation boundaries occurring at one or other of these contacts. However, not all sequence-level sandstone / shellbed contacts are mappable, and therefore in some cases the units (formations) mapped are aggregates of sequences.

The stratigraphic nomenclature of Fleming (1953) established in the western part of the basin has been retained as much as possible. For the eastern part of the basin the lithostratigraphy of Naish & Kamp (1995) and Journeaux et al. (1995) has been adopted and in places emended. The level of stratigraphic subdivision in this study means that formally naming each member of each formation would be excessive, so each member has an alphanumeric lithostratigraphic code. This is separated into three parts, which refer to the formation, lithology and stratigraphic position of the member within the formation. For example, *Atzm2* refers to the second siltstone *(z)* member from the base of of the Atene Formation *(At)*. Similarly, *Pkcm3* refers to the third shellbed (*c* - coquina) member from the base of the Parikino Formation *(Pk)*.

No maps or columns are included within this chapter, but are presented in two large enclosures in the back of the thesis. Enclosure 1 includes stratigraphic columns from each section investigated in this study, and illustrates the lateral distribution of the units described in this chapter. These stratigraphic columns are complemented by a series of new geological maps, which comprise Enclosure 2. The geological maps illustrate the spatial distribution of the formations described in this chapter, and are linked to Enclosure 1 by the formational lithostratigrapy presented in figure 3.1.

History of late Pliocene Wanganui Basin stratigraphic subdivision:

The richly fossiliferous strata in the Wanganui basin began to attract interest from macropalentologists in the mid-late 1800s (Buchanan, 1870; Hector, 1870; Marshall & Murdoch, 1920; Laws, 1940). Consequently, most early studies in the basin were palentologically based, small-scaled, and confined to exposures in coastal cliffs, and comparatively little emphasis was placed on large-scale stratigraphic subdivision. The exception to this was Park (1887; 1905; 1910), who erected a very simple stratigraphic framework, with his "Waitotara Crags" series incorporating all the strata examined in this study. While much progress in molluscan biostratigraphy was made by these early studies, and many of the New Zealand Stage classification names derived from the succession (e.g. Waitotaran, Nukumaruan) they added little new stratigraphic information. More detailed history of these earlier studies and their significance is outlined in the chapters focusing on the Mangapani Shell Conglomerate, Wilkies Shellbed and Hautawa Shellbed (Chapters 5-7).

In 1943, the Superior Oil Company published a report on the Wanganui Basin (Feldmeyer *et al.* 1943), which greatly increased the understanding of the geology of the late Miocene, Pliocene and Pleistocene parts of the basin, with emphasis on the strata exposed in the Rangitikei, Turakina, Mangawhero and Wanganui River valleys. Using a combination of lithostratigraphy and foraminiferal biostratigraphy, this study identified seven foraminiferal zones, which were attributed to contemporary NZ Stages, but no correlation between the inland sections investigated in this study and the established coastal section was made.

The greatest single contribution to the understanding of the geology of the Wanganui Basin was made by Fleming (1953), who focused on the lithostratigraphy, molluscan biostratigraphy and paleoecology of the Plio-Pleistocene strata in the vicinity of Wanganui City, mapping strata from the coast at Waverly, inland to the Turakina River valley. This work led to great advancements in the refinement of the New Zealand geological timescale, with substantial collections of fossil molluscs collected from the richly fossiliferous strata. This work built substantially upon the existing stratigraphy of Feldmeyer *et al.* (1943), and forms the basis for the stratigraphic subdivision presented in this study. Wherever possible this lithostratigraphy has been retained in this study, but changes have had to be made to enable a stratigraphic synthesis to emerge that can accommodate the lithological changes across the basin. For example, the Paparangi Subgroup as used in this study is essentially identical to the Paparangi Group of Fleming (1953); the only change is its demotion to a Subgroup of the Taihape Group. In addition, its upper boundary shifts from the upper to the lower contact of the Wilkies Shellbed. The demotion of Fleming's Groups to Subgroups is necessary because of the erection of the Taihape Group of Kamp *et al.* (in prep), which encompasses all strata between the top of the "Number One Reef" of the Matemateonga Formation and the base of the Hautawa Shellbed of the Whariki Formation, Rangitikei Group.

Ker (1973) re-examined the strata in the lower Wanganui River between Koroniti and Parikino in the Wanganui River valley, and produced a geological map of the strata in the immediate vicinity of the river. This study added little new data to that of Fleming (1953), except for the description of the Cable Siltstone, which lies between the Wilkies Shellbed and Te Rimu Sandstone, both of which were described by Fleming (1953).

The advent of sequence stratigraphy and the subsequent recognition of the cyclothemic nature of the strata in Wanganui basin have led to closer re-examination of its succession (Kamp and Turner, 1990; Abbott and Carter, 1994; Naish and Kamp, 1997; Journeaux *et al.* 1996; McIntyre & Kamp, 1998). The most relevant of these more recent studies in terms of the stratigraphic framework proposed for the Nukumaruan (late Pliocene-early Pleistocene) strata in the basin is the one by Naish & Kamp (1995), who subdivided the cyclothemic strata in the Rangitikei River valley between Mangaweka and Hunterville. However, their lower units are shown here not to be particularly applicable to western Wanganui Basin strata, and so the lithostratigraphy of McIntyre & Kamp (1998) has been developed from the base of the Mangapani Shell Conglomerate to the base of the Ohingaiti Sandstone in this study. The lithostratigraphy used in Feldmeyer *et al.* (1943) and Fleming (1953) is summarised in figure 3.1, which also presents the formational lithostratigraphy developed and used in this study.

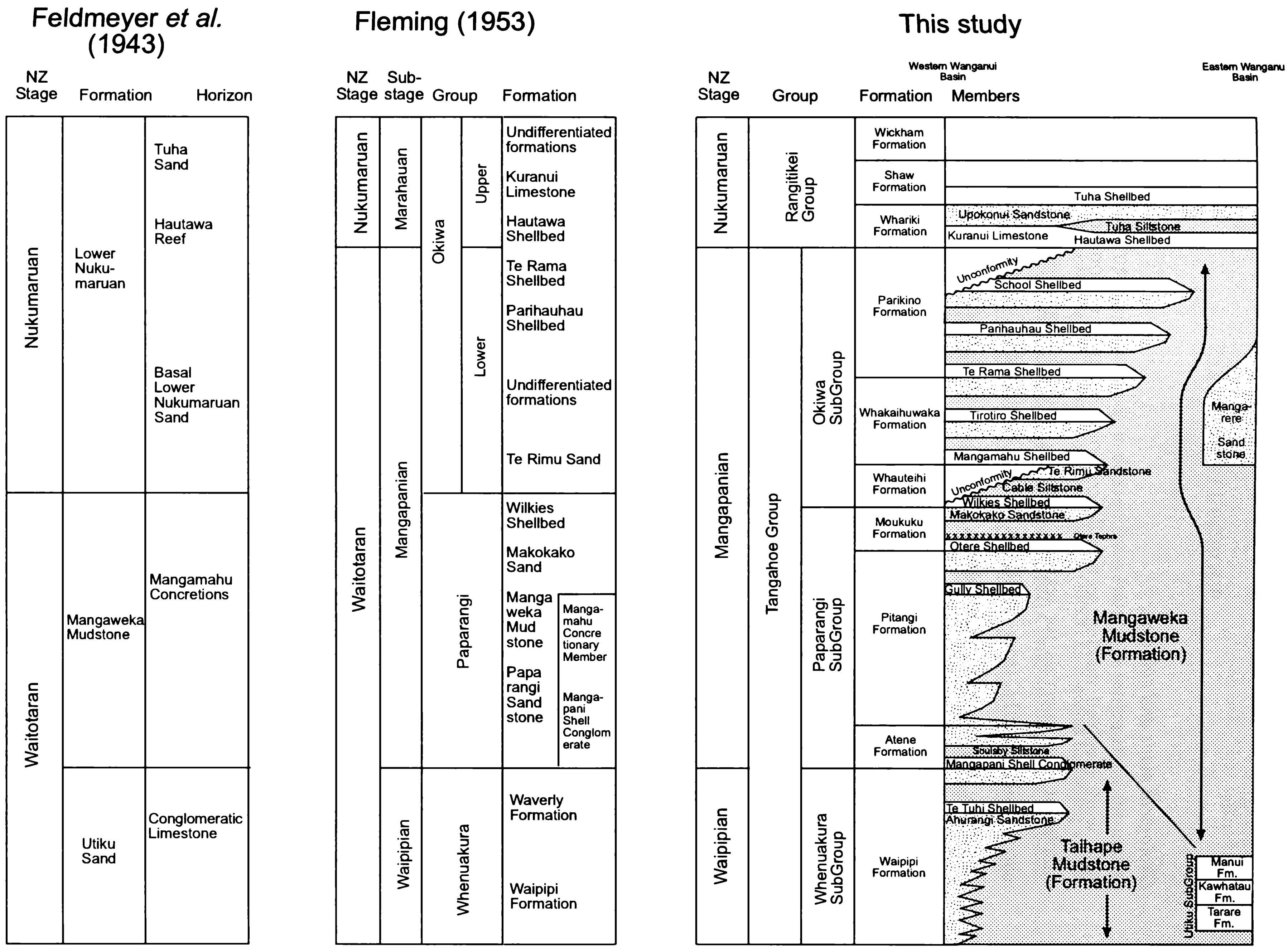

Figure 3.1: Historical and proposed lithostratigraphy, Mangapanian and lower Nukumaruan Stages, Wanganui Basin.

Geological maps and columns:

Field work involved making section descriptions, mapping of formations, collection of samples at 2 m intervals for textural analysis, facies descriptions and the collection of macrofossils, chiefly from shellbeds. The stratigraphic columns are assembled on Enclosure 1 in the back of the thesis. The maps are reproduced on Enclosure 2. The Wanganui River valley stratigraphy of McIntyre & Kamp (1998) was used as a starting point for description and mapping of Mangapanian and early Nukumaruan Stage strata within each major valley west of Wanganui valley. The textural analysis of samples helped in the refinement of the stratigraphy. In particular, the simple sand / silt ratio curve clearly shows the major lithological changes evident in the field. Thickness estimates of units were made with a pogo stick and tape measure, and checked against topographic maps with 20 m contours (NZMS 260). The same procedures were applied to the Mangapanian and early Nukumaruan Stage strata east of Wanganui valley. The field stratigraphy combined with the textural data has enabled robust correlations to be made between various sections as displayed on Enclosure 1. Enclosure 2 illustrates a series of geological maps of particular areas, covering several major river valleys. The columns and maps illustrate the formal lithostratigraphy described in the following sections of this chapter.

PAPARANGI SUBGROUP.

(emended)

NAME: The name Paparangi Subgroup is derived from Paparangi settlement in the upper Kai-iwi valley, and was originally proposed by Fleming (1953) as a group including strata stratigraphically between and including the Mangapani Shell Conglomerate at the base and the Cable Siltstone Member at the top. In the east where these units are not present, the laterally equivalent Mangaweka Mudstone is also included in this group. Generally, the Paparangi Subgroup refers to the sparsely fossiliferous Mangapanian strata in the basin, and is emended here to not include the Wilkies Shellbed. The top of the Subgroup is shifted downward to the base of the Wilkies Shellbed, which is a more easily mappable contact than the top of the shellbed. As part of a stratigraphic revision of the whole basin (Kamp *et al.* in prep) the Paparangi Group of Fleming (1953) has been demoted to subgroup status. (Maori: Papa = base or flat surface, rangi = air).

TYPE LOCALITY AND DISTRIBUTION: Continuous exposure of the Paparangi Subgroup in Wanganui Basin is rare. Fleming (1953, p. 116) made the Waitotara valley the type section for the Subgroup, which is retained here despite poor exposure of its upper part. However, strata not exposed on the coast due to the wide gap at the Waitotara River mouth crop out in an escarpment below Okiwa Trig. Further east, the Paparangi Subgroup grades laterally into the Mangaweka Mudstone. In the Rangitikei River valley the top of the Mangaweka Mudstone is extended upwards to the base of the Hautawa Shellbed. As part of this change the Mangarere Formation of Naish & Kamp (1995), who had this unit between the Mangaweka Mudstone and Hautawa Shellbed, is demoted to a member of the Mangaweka Mudstone Formation and its extent limited to the sandy lower part (Figure 3.1).

THICKNESS: 600 m (Rangitikei), 800 m (Turakina), 500 m (Wanganui), 240 m (Wairangi), unknown, but > 280 m (Waitotara).

AGE: early-middle Mangapanian.

LITHOLOGY: The Paparangi Subgroup varies across the basin, from sandstone-dominated in the west, to almost completely siltstone in Turakina and Rangitikei valleys. In Waitotara valley and at Wairangi, six sandstone and siltstone units of variable thickness alternate with the contact between most lithologies being conformable, and barren. Shellbeds are rare, and with the exception of the Mangapani Shell Conglomerate, occur in the upper part of the subgroup, and contain diverse molluscan assemblages. Siltstone lithologies range from fine-grained in the east, to sandy siltstone in the west, and coarsen upward into fine sandstone. Both siltstone and sandstone lithologies are sparsely fossiliferous to barren, massive, and moderate to poorly cemented.

CONSTITUENT FORMATIONS: *Western parts of Wanganui Basin*: Atene Formation, Pitangi Formation, Moukuku Formation.
Eastern parts: Mangaweka Mudstone.

ATENE FORMATION.

(emended from Hayton, 1998)

NAME: The Atene Formation was applied by Feldmeyer *et al.* (1943) to sandstone beds cropping out at Atene, in the Wanganui River valley. They named it the "Atene Sand", a name that was slightly modified to "Atene Sandstone" by Ker (1973), and "Atene Formation" by Hayton (1998). In this study, the correlation of the Mangapani Shell Conglomerate with a thin shellbed between the two main sandstone beds has necessitated partitioning of the Atene Sandstone, with the name Atene Formation retained and emended to apply to strata between the Mangapani Shell Conglomerate and Mangaweka Mudstone. The lower sandstone becomes part of the Waipipi Formation. (Maori: Atene = Athens).

TYPE LOCALITY AND DISTRIBUTION: The original type locality at Atene, Wanganui River (S21/937624) is retained. It occurs in an abandoned oxbow of the Wanganui River. The base of the formation is marked by the Mangapani Shell Conglomerate at S21/924633, and the top by two prominent concretionary sandstone horizons in bluffs above the oxbow at the type section. The Atene Formation is also well exposed in a large scarp beside the Kauarapaoa valley road (R21/872624), where the upper sandstone part of the formation crops out. The two thin sandstone horizons that mark the top of the formation crop out intermittently for several kilometres in slopes above the entrance to Wairangi Station. In Waitotara valley, the two upper sandstone horizons are much thicker, but the Atene Formation is able to be distinguished from the Pitangi Formation. Sandstone belonging to the Atene Formation also crops out in the Mangawhero valley. It crops out on the SH4 roadside about 4 km south of Otoko at Site 53 (S22/090580). It does not occur to the east of this locality.

THICKNESS: 42 m (Mangawhero, from Feldmeyer *et al.* 1943), 110 m (Wanganui, from Hayton, 1998), 72 m (Wairangi), 73 m (Waitotara).

AGE: early Mangapanian.

LITHOLOGY: The Atene Formation is comprised of a shellbed member (Mangapani Shell Conglomerate), and several siltstone and sandstone members, including the Soulsby Siltstone and Atene Sandstone Members.

Mangapani Shell Conglomerate Member.

(Atcm1)

NAME: Laws (1940) identified and collected fossil molluscs from fossiliferous "beds at Mangapani", which Fleming (1953) formally named "Mangapani Shell Conglomerate", a name that has been retained by all subsequent workers. The name is retained here in favour of "Mangapani Shellbed", as it draws necessary attention to the pebbly matrix, a rare occurrence in Wanganui Basin shellbeds. (Maori: Manga = creek / watercourse, pani = orphan. Some references to the valley - "Mangapunipuni", where punipuni = brood, litter or flotsam).

TYPE LOCALITY AND DISTRIBUTION: Fleming (1953) formalised the section visited by Laws (1940) as the type locality of the Mangapani Shell Conglomerate in the Mangapunipuni valley at site 3 (R21/671613), where the shellbed crops out intermittently along the true left valley wall. The shellbed also crops out on the Waitotara valley roadside at site 2 (R21/660604), and in many sections to the northwest of Waitotara township. The most notable is an abandoned quarry at site 1 (R22/570553) 2 kms north of Waitotara, the westernmost exposure, in a gully about 500 m north of SH3. New localities identified in this study include Wairangi, where the shellbed crops out at the base of a waterfall near a woolshed at site 20 (R21/846625), and on the Wanganui River valley roadside at site 35 (S21/924633), about 2.5 km north of Atene settlement. A sharp-based sandstone at the south end of a ~ 1 km long straight on Highway 4 (S22/094592) is probably a highly weathered and leached correlative of the Mangapani Shell Conglomerate, but lack of fossils precludes confirmation of this correlation.

THICKNESS: 2.5 m (Wanganui), 0.5 m (Wairangi), 6 m (Mangapunipuni), 4.5 m (Waitotara), 10 m (Highway 3).

AGE: early Wm (Mangapanian). First occurrences of *Phialopecten thomsoni, Tawera subsulcata, Pelicaria* n.sp. aff. *zelandiae,* and *Penion sulcatus.*

LITHOLOGY: (n.b. The following is a summary of more detailed descriptions, in Chapter 5).

A wide diversity of fossils and of matrix lithologies comprise the Mangapani Shell Conglomerate. The shellbed collectively has several parts with different facies and faunal content. In all sections where the shellbed occurs it is unconformable on the underlying Whenuakura Subgroup. In the Wanganui River valley, the Mangapani Shell Conglomerate is poorly developed and sparsely fossiliferous, with an impoverished faunal assemblage. The lower part of the shellbed is leached, with rare casts of *Divaricella* in a 0.5 m thick silty sandstone unconformably overlying Whenuakura Subgroup sandstone. The main part of the shellbed is in siltstone sharply overlying this sandstone, with rare specimens of *Penion, Pelicaria, Chlamys, Ostrea, Atrina* and clumps of *Pratulum* occurring together with small (< 5 mm), well rounded greywacke pebbles. At Wairangi, the shellbed is thinner, and grades from a thin (0.25 m thick) shellbed with common *Divaricella* and pebbles (< 13 mm diameter) into a *Crassostrea*-dominated upper part of similar thickness. The shellbed thickens dramatically eastward into the type section at Mangapunipuni valley, where the lower part is 0.6 m thick, and comprises a coarse micaceous sandstone and pebble matrix supporting disarticulated abundant *Tucetona, Maoricardium, Eumarcia* and *Crepidula,* with greywacke pebbles averaging < 22 mm diameter. The upper part of the shellbed at this locality is more cemented, and forms a shell hash limestone with abundant *Phialopecten thomsoni* at its base. This limestone is 5 m thick, and also contains Bryozoa and rare *Atrina* and *Crassostrea* throughout. This pattern is repeated on the Waitotara valley roadside, with the lower part being 0.4 m thick, and containing a similar fauna to the type section, with the addition of *Paphies,* and an increase in pebble diameter to < 30 mm. There, the upper limestone part is 2.5 m thick, has the same appearance and fauna as the type section, and is separated from the lower shellbed by an intervening 1.4 m thick sandstone with 10 cm thick beds of alternating sandstone and siltstone. At Waitotara, the facies has changed, with the unit being a sandy shell gravel hash limestone some 10 m thick, with poorly preserved fossils. There, northward facing, high-angle, decimetre scale foresets with rare casts and fragments of *Phialopecten thomsoni, Perna, Ostrea* and *Sigapatella* comprise the lower 4 m, passing upwards into a bi-directional, shallow-dipping, herringbone cross-stratified limestone with increasing terrigenous material toward the top.

DEPOSITIONAL ENVIRONMENT: The Mangapani Shell Conglomerate was deposited during a transgression, as indicated by the progressively deeper shelf faunal assemblages upsection within the shellbed. The occurrence of the lowermost sandstone part and the increase in pebble diameter westward shows that the transgression probably progressed westward, and reached a highstand shoreline in the vicinity of the present Waitotara Township. Molluscs in the shellbed are generally open marine, with the exception of the lower sandstone part in Waitotara valley, where rare, abraded *Austrovenus, Xymene, Micrelenchus, Zeacumantus,* and *Cominella* indicate the reworking of estuarine taxa into the open shoreface environment. Water depths as shallow as 3 m are inferred from the presence of *Zethalia* and *Fellaster* in the base of the shellbed in Waitotara valley. Fossils from the shellbed in Wanganui River valley suggest a depth of deposition of 30 - 50 m at the top of the shellbed.

Soulsby Siltstone Member.

(*Atzm 1*,new) and other siltstone members. (*Atzm2, 3*)

NAME: The name "Soulsby Siltstone Member" is proposed for the siltstone units conformably overlying the Mangapani Shell Conglomerate. The name is taken from the current owner of Wairangi Station, on whose land the type locality occurs. The Soulsby Siltstone Member is equivalent to the upper part of the abandoned Mangapapa Siltstone of Collen (1972).

TYPE LOCALITY AND DISTRIBUTION: The type locality is at Wairangi Station in an unnamed tributary of the Kauarapaoa Stream at site 20 (R21/846625), where a small creek and waterfall flow through and over the Soulsby Siltstone. The base of the unit also crops out on the Wanganui River valley roadside at site 35 (S2/924633); the upper part crops out poorly on the roadside for several hundred metres south of this site, and in a small creek behind the Atene Marae at (S21/937624) (Hayton, 1998). The two upper siltstones interbedded with sandstone near the top of the Atene Formation are flaser-bedded, with 1 cm alternations of rippled sandstone and siltstone drapes. In Waitotara valley, the Soulsby Siltstone Member crops out variably on hillsides in the vicinity of site 2 (R21/660604).

THICKNESS: *Atzm1* (Soulsby Siltstone): 40 m (Wanganui), 38 m (Wairangi), 1 m (Waitotara).

Atzm2: 4 m (Wanganui), 11 m (Wairangi), 6 m (Waitotara).

Atzm3: 3 m (Wanganui), 6 m (Wairangi), 6 m (Waitotara).

AGE: early Mangapanian.

LITHOLOGY: Featureless, massive, moderately cemented, bioturbated, variably concretionary, blue-grey siltstone. In places texture coarsens to sandy siltstone. Sparsely fossiliferous, with rare *Pelicaria, Atrina* and *Pratulum* found throughout. Common foraminifera include *Cassidulina neocarinata, Elphidium charlottense, Nonionella flemingi, Notorotalia finlayi, Uvigerina rodleyi* and *Virgulopsis* spp. (Foraminifera from Wanganui River valley; Hayton, 1998).

DEPOSITIONAL ENVIRONMENT: The foraminiferal assemblage (Hayton, 1998) indicates mid-outer shelf accumulation at water depths of between 50 - 100 m. However, molluscan assemblages suggest a water depth of 30 - 50 m. Thus a depth of around 50 m is inferred, at the inner-mid shelf transition. The rare presence of both molluscs and foraminifera indicates that the sediment accumulation rate and / or turbidity was high, but low enough to permit the survival of a few species in low numbers. The flaser-bedded siltstone units (*Atzm 2,3*) indicate an intertidal to subtidal depositional environment, meaning that the contemporary water depth shallowed significantly during accumulation of these members.

Atene Sandstone Member.

(*Atsm1, 2, 3*)

NAME: The name Atene Sandstone Member is applied here to sandstone beds stratigraphically between the Soulsby Siltstone Member and Mangaweka Mudstone. Feldmeyer *et al.* (1943) and Ker (1973) included sandstone beds beneath the Soulsby Siltstone Member in their "Atene Sands", but the identification of the Mangapani Shell

Conglomerate between these two sandstone beds (this study) has necessitated rationalising the name Atene Sandstone and its restriction to the upper sandstone, following the practice of Collen (1972). This sandstone was referred to as *Asm3* by Hayton (1998). (Maori: Atene = Athens).

TYPE LOCALITY AND DISTRIBUTION: The original type locality of Ker (1972) at S21/932633 has been covered by regenerating bush and is difficult to access. Consequently, a reference section beside Atene Pa (S21/637624) has been suggested (Hayton, 1998). Exposure of the Atene Sandstone Member is generally poor in this vicinity, as it crops out intermittently in the valley walls of the oxbow, where two prominent thin sandstone horizons above the main (lower) Atene Sandstone Member mark the top of the Atene Formation. There is good exposure of the Atene Sandstone Member in a rapidly eroding road cutting in Kauarapaoa valley at R21/872624. It also crops out variably near the base of the hillside above Wairangi Station, and in a cutting at the northernmost end of the abandoned part of Tokomaru East Road at Wairangi. In Waitotara valley, the Atene Sandstone Member is not well exposed, but crops out poorly above the roadside at R22/668598, at the confluence of the Mangaone Stream with Waitotara River. To the east of Wanganui valley, the lower Atene Sandstone member is well exposed on Highway 4 roadside at S22/090580, but the upper and lower boundaries are concealed.

THICKNESS:
Atsm1 (Atene Sandstone): > 25 m (Mangawhero), 49 m (Wanganui), > 30 m (Kauarapaoa), 13 m (Wairangi), 34 m (Waitotara).
Atsm2: 3 m (Wanganui), 4 m (Wairangi), 6 m (Waitotara).
Atsm3: 3 m (Wanganui), 1 m (Wairangi), 4 m (Waitotara).

AGE: early Mangapanian.

LITHOLOGY: Typically, the Atene Sandstone Member is a bioturbated, fossiliferous, massive, blue-grey micaceous sandstone, which weathers to a yellow-brown sandstone. It conformably overlies the Soulsby Siltstone, and is easily differentiated from other mass-emplaced sandstone in the central Wanganui Basin by containing rare molluscs, and by having a gradational base. In Mangawhero valley, the lower Atene Sandstone Member contains rare *Pelicaria* and bivalves (*Cyclomactra*?), the latter occurring in thin lenses. In Wanganui valley, the sandstone reaches its maximum combined thickness, and forms steep bluffs above the Atene oxbow, with the two thin sandstone members cropping out visibly and forming a dip-slope above the lower Atene Sandstone Member. At the roadside locality in Kauarapaoa valley, subtle low-angle trough cross-beds occur in the upper part of the lower sandstone bed in the easternmost part of the bluffs above the stream, and the two thin upper sandstone units are visible on the south bank of the Kauarapaoa Stream, where they variably protrude out of the hillside between this locality and Wairangi Station. At Wairangi, the Atene Sandstone Member is much thinner and siltier, with no obvious bedding features, and the two upper sandstone members are sharply interbedded within the intervening siltstones. In Waitotara valley, the Atene Sandstone Member is well weathered, moderately cemented, and exhibits no bedding features.

DEPOSITIONAL ENVIRONMENT: A shallow, inner-shelf to shoreface environment is inferred for the Atene Sandstone Member, with a possible estuarine influence if the indeterminate bivalves are in fact *Cyclomactra.* The alternations between siltstone and sandstone at the top of the formation probably represent minor perturbations in sea-level and parasequence development in the near-shore environment. This interpretation is reinforced by the occurrence of trough cross-bedding in the upper part of the sandstone in Kauarapaoa valley, which indicates reworking in near-shore conditions.

MANGAWEKA MUDSTONE.

(emended)

NAME: The name "Mangaweka Mud" was originally applied by Feldmeyer *et al.* (1943) to the thick mudstone unit between the Utiku Sandstone and "Basal Nukumaruan Sands" (now Okiwa Subgroup) near Mangaweka. They traced it eastward into the Turakina valley. Fleming (1953) emended the name to "Mangaweka Mudstone", and extended its definition to include the siltstone between the Atene Formation and Okiwa Subgroup in Wanganui and Mangawhero valleys, a practice which Feldmeyer *et al.* (1943) avoided. In the Whangaehu valley, Fleming (1953, p. 121) also referred to the Mangaweka Mudstone, despite the occurrence of neither the Utiku Subgroup nor Atene Formation in this section. The name "Mangaweka Mudstone" has been retained by the majority of subsequent workers despite this anomaly (e.g. Ker, 1972; Thompson *et al.* 1994; Journeaux *et al.* 1996; Hayton, 1998) and is also retained in this study. The names "Pitangi Mudstone" of Collen (1972) and "Otawake Mudstone" of Wilson (1993) are not used in this study. In this study, the Mangarere Formation of Naish & Kamp (1995) is included within the Mangaweka

Mudstone, but this name is retained for a sandstone bed (Mangarere Sandstone Member) in the lower part of the original Mangarere Formation, and the formation abandoned. (Maori: Manga = creek, weka = NZ woodhen *Gallirallus australis*).

TYPE SECTION AND DISTRIBUTION: A type section for the Mangaweka Mudstone was not designated by Feldmeyer *et al.* (1943). Journeaux *et al.* (1996) set up a type section as the riverbanks extending from 300 m south of the South Rangitikei viaduct (T22/507523) to a bluff on the riverbank opposite Weston Road (T22/466473). However, the extension of the Mangaweka Mudstone to include the Mangarere Formation of Naish & Kamp (1995) means that this should be extended southward in river banks to T22/436457. In Turakina valley, the Mangaweka Mudstone extends from the top of the Utiku Sandstone 2 km south of Papanui Junction (S21/277659) up to the base of the Okiwa Subgroup at S22/228532, forming a characteristic landscape of steep-sided narrow valleys and waterfalls. The base of the Mangaweka Mudstone essentially continues down into the Tangahoe Mudstone in the Whangaehu River valley. The upper contact with the Pitangi Formation occurs near Omahanui, several kilometres north of Mangamahu settlement. Likewise, only the very top of the Mangaweka Mudstone occurs at Parihauhau, and the contact between it and the Pitangi Formation was not observed. In the Wanganui River valley, it is poorly exposed between Atene and the confluence of the Pitangi Stream and Wanganui River, the top occurring in the base of a riverbank beneath the Pitangi Stream Bridge (S22/958582). Ker (1973) designated a locality in the hillside on the east face of the ridge separating the oxbow from the Wanganui River, which is an unsuitable type locality because it does not include the whole stratigraphic range of the unit and is covered by regenerating bush (Hayton, 1998) and thus must be abandoned in favour of the Rangitikei River valley locality. The top of the Mangaweka Mudstone forms the steep, canyon-like banks of the Kauarapaoa Stream at R22/900505, but rapidly loses character west of this locality, coarsening laterally into the sandstone-dominated Pitangi Formation. The last occurrence of the benthic foraminifer *Cibicides molestus* beneath the Mangaweka Mudstone in the Wanganui River valley (Hayton, 1998) and within it in the Rangitikei River valley (Journeaux *et al.* 1996), demonstrates that the base of the Mangaweka Mudstone is diachronus. The top of the unit is also diachronus, but less so than the base, being overlain by Okiwa Subgroup strata in the Turakina valley, and the Pitangi Formation west of the Whangaehu valley.

THICKNESS: 600 m (Rangitikei), 800 m (Turakina), both above Utiku Sandstone. 330 m (Wanganui River), above Atene Formation.

AGE: late Waipipian to late Mangapanian in Rangitikei and Turakina valleys; early to middle Mangapanian in Wanganui River valley.

LITHOLOGY: The Mangaweka Mudstone maintains a uniform character in outcrop across the central to eastern parts of the basin, being a slightly cemented, massive, bioturbated, sparsely fossiliferous blue-grey mudstone. Concretionary horizons are variably common, with most concretions being spheroidal and between 0.1 and 1 m in diameter. Grainsize alternates rhythmically between siltstone and sandy siltstone, especially in the Rangitikei valley, where seven 41 k.y. sedimentary cycles have been identified by grainsize analysis (Journeaux *et al.* 1996). In the Wanganui River valley, three 41. k.y. sedimentary cycles comprise the Mangaweka Mudstone, which emphasises the diachronaeity of the unit across the basin. Collen (1972) and Hayton (1998) both report a low foraminiferal content in the Wanganui River valley for this unit, as do Kamp *et al.* (1998) for the unit in the Rangitikei River valley. Naish & Kamp (1995) report the occurrence of *Lucinoma. galathea* and *Pratulum pulchellum* in the Mangaweka Mudstone (formerly Mangarere Formation) immediately above the Mangarere Sandstone Member in the Rangitikei River valley. Feldmeyer *et al.*. (1943) and Fleming (1953) describe a mappable concretionary member within the Mangaweka Mudstone, the "Mangamahu Concretionary Horizon". Journeaux *et al.*. (1996) correlated a prominent concretionary horizon 140 m below the top of the Mangaweka Mudstone in the Rangitikei River valley with this unit, but it is not present west of the Rangitkiei River valley. Two tephras, (Kowhai and Eagle Hill Tephras) described by Journeaux *et al.* (1996) at Mangaweka were collected and attempts were made to date (U-Pb SHRIMP; U/Th-He) the Eagle Hill Tephra radiometrically (see Chapter 4).

DEPOSITIONAL ENVIRONMENT: The rapid change in facies from sandstone to siltstone separating the top of the Utiku Subgroup and the top of the Atene Formation from the Mangaweka Mudstone across the basin is interpreted as the result of rapid, tectonically driven deepening, marked by a decrease in grain size and by an outer shelf foraminiferal assemblage overlying shoreface deposits in both the Rangitikei and Wanganui River sections. In Rangitikei valley, the Mangaweka Mudstone has an inferred depth of deposition of 125 - 200 m. The rapid increase in waterdepth is discussed in detail in Kamp *et al.* (1998). For the upper part of the Rangitikei River section, molluscan data are sparse, but the occurrence of *Lucinoma galathea* and *Pratulum pulchellum* above the Mangarere Sandstone Member indicates fine-grained, outer-shelf depositional conditions. In

Wanganui River valley, the low foraminiferal content precludes precise determination of the depth of deposition for the Mangaweka Mudstone, which is interpreted as being affected by an abnormally high rate of sediment accumulation. However, foraminiferal census data for the samples from the unit in this section give an interpreted depositional depth of ~ 100 m (Hayton, 1998). Low foraminiferal diversity was reported by both Collen (1972) and Kamp *et al.* (1998) for the Mangaweka Mudstone, both studies concluding that low foraminiferal diversity and content indicate a degree of isolation for the basin during accumulation of the Mangaweka Mudstone.

Mangarere Sandstone Member.

(emended)

NAME: The name Mangarere Formation was established by Naish & Kamp (1995) for a 220 m thick unit overlying the Mangaweka Mudstone in Rangitikei River valley. The name is derived from Mangarere Stream, a tributary of the Rangitikei near Mangaweka township (Naish & Kamp, 1995). Subsequently, the name Mangarere Sandstone has also been informally applied to the sandstone comprising the lower part of the formation (Carter & Naish, 1998; Naish, pers. comm.), a usage formalised here. The sandstone itself was first identified by Feldmeyer *et al.* (1943), and originally named the "Basal Nukumaruan Sand". Fleming (1953) correlated the "Basal Nukumaruan Sand" with the "Te Rimu Sand" in Wanganui valley. This usage was adopted by Naish & Kamp (1995). However, McIntyre & Kamp (1998, p.83) pointed out that the sandstone near Mangaweka had been miscorrelated with the type Te Rimu Sandstone in Wanganui River, necessitating a name change for the sandstone (to Mangarere Sandstone Member) in the Rangitikei River section. (Maori: Manga = creek, rere = dive / dash).

TYPE SECTION AND DISTRIBUTION: The Mangarere Sandstone Member is restricted to the Rangitikei River valley, with the type section on Mangarere Road at T22/500474. Other localities include T22/476475 and T22/466473, both near the eastern bank of the Rangitkiei River (Naish & Kamp, 1995), and in the Porewa valley on the West Road roadside between T22/345476 and T22/339479.

THICKNESS: 110 m (Rangitikei), 75 m (Porewa).

AGE: middle-Mangapanian.

LITHOLOGY: The Mangarere Sandstone Member has an unconformable base, and lies within Mangaweka Mudstone. A 1 m-thick concretionary sandstone bed marks the base of a poorly cemented, moderately well-sorted (at base), brown-grey, medium-grained, low-angle and trough-cross stratified to parallel-laminated sandstone, which grades upsection into massive silty sandstone. At the type section, the base of the unit is locally channelised (up to 30 m) into the Mangaweka Mudstone, with large unoriented mudstone clasts of up to 2 m in diameter within a silty sandstone matrix, overlain by wavy-laminated sand and silt interbeds. These interbeds pass upsection into cross-stratified, locally cemented, coarse bioclastic sands lenses within silty sandstone, grading upwards into larger scale, low angle, cross-stratified sandstone (Naish & Kamp, 1995). Above this, the sandstone is massive and barren, with a barren interval of 104 m between the very top and the base. Common foraminiferal taxa in the lower 1 m of the sandstone include *Ammonia, Astronion, Cibicides, Elphidium, Notorotalia,* and *Zeaflorilus,* with *Anomalinoidies, Astronion, Elphidium, Lagena, Nonionella, Notorotalia* and *Uvigerina* occurring at the very top of the unit, just below the transition to siltstone (Naish, 1996). The top of the Mangarere Sandstone grades back into Mangaweka Mudstone over a distance of 40 m. In Porewa valley, the sandstone is less well exposed, but crops out on the roadside as a barren, well sorted, slightly cemented, yellow-brown fine sandstone. The base of the sandstone is not well exposed, but large-scale trough bedding is present near the base, passing upsection into massive sandstone normally grading into siltstone in much the same manner as its correlative in the Rangitikei River.

DEPOSITIONAL ENVIRONMENT: The depositional environment of the Mangarere Sandstone is problematic. Here, the Mangarere Sandstone Member is interpreted as a slope channel deposit, as shown by the channel incised into Mangaweka Mudstone. The large siltstone blocks in the channel itself are probably derived from the Mangaweka Mudstone. Where the channel is not present, channel meandering possibly cut the unconformity at the base of the sandstone, a surface that was subsequently covered by sandy over-bank deposits in response to channel migration on the outer-shelf / upper slope. Channel migration and lobe switching are possible causes of the cross-bedding, lenses and laminations at the base of the sandstone (which is barren in the upper parts), with the gradual normal gradation from sandstone to siltstone at the top of the unit possibly reflecting a slow decrease in sediment supply or regional migration of the channel away from this locality. The presence of shallow-water, estuarine benthic foraminifera is somewhat anomalous, but they possibly have been reworked from innermost shelf environments or deposits.

PITANGI FORMATION.

(replaces Paparangi Sandstone)

NAME: The Pitangi Formation was established by McIntyre & Kamp (1998) to replace the Paparangi Sandstone, and thus avoid confusion between the Paparangi Sandstone and Paparangi Group of Fleming (1953). The name is derived from Pitangi Stream, which enters the Wanganui River at Te Rimu. It is applied to sandstone-dominated cyclothemic strata between the top of the Atene Formation and the base of the Moukuku Formation, and is generally laterally equivalent to the Mangaweka Mudstone. The Pitangi Formation is overlain by the base of the Otere Shellbed (Moukuku Formation). (Maori: Pi = corner, tangi = cry. A Maori Pa (fortified village) at this locality governed by the chieftain Rakautauria was overrun by a hostile tribe sometime between 1800 and 1810) (Downes, 1915).

TYPE SECTION AND DISTRIBUTION: Fleming (1953, p. 114) gave the type locality for the Paparangi Subgroup and Sandstone as the Paparangi district in the upper Kai-iwi valley, where it forms a characteristic topography of smooth, bare, lichen-encrusted, rounded ridge crests, which readily revert to scrub. The change in name from Paparangi Sandstone to Pitangi Formation accompanies a new type locality, which is designated as the sandstone gradationally overlying the Mangaweka Mudstone beneath the Pitangi Stream Bridge (S22/958582), and the Whauteihi Stream Bridge, south alongside the Wanganui River Road. The top of the Pitangi Formation is well exposed at the Whauteihi stream mouth. Only the uppermost sandstone of the Pitangi Formation occurs in the Whangaehu River valley section, where sandstone conformably overlies the Mangaweka Mudstone at Omahanui, which is the easternmost expression of the Pitangi Formation. The Pitangi Formation is not well exposed in Kauarapaoa valley, but crops out on northward facing ridge crests on the true right hand side of the valley. At Wairangi, the entire Pitangi Formation is accessible in cuttings on the abandoned northern part of Tokomaru East Road leading up from Wairangi Station to Ruawahia Trig, but is rapidly becoming overgrown. At Paparangi, exposure of the Pitangi Formation is generally poor, with the incompetent sandstone slumped in roadside cuttings to obscure the strata. Furthermore, the base of the formation is either not exposed or is indistinct from the Atene Formation at this locality, making it an unsuitable type section. At Okiwa Trig, the upper parts of the Pitangi Formation are well exposed in a large gully beneath the trig station, and contains the only known exposure of the Gully Shellbed Member (new, this study) about 40 m from the top of the formation, which is conformably overlain by the Otere Shellbed (Moukuku Formation). The formation crops out in road cuttings beside the Waitotara valley Road from near the mouth of Mangaone Stream to the roadside bluffs where the State Highway 3 Bridge crosses the Waitotara River, with the upper part concealed by river flats and sand dunes. Two thin shellbeds, a thin *Crassostrea* shellbed, 0.2 m thick at (R22/640575) and a poorly developed shell horizon separating sandstone from siltstone at R22/662562 are the only significant fossil accumulations apart from the Gully Shellbed within the Pitangi Formation.

THICKNESS: (Total): 10 m (Whangaehu), 38.5 m (Wanganui), 138 m (Wairangi), >> 64 m (Okiwa), > 162 m (Waitotara).
Ptzm1: 41 m (Wairangi), 35 m (Waitotara).
Ptsm1: 17 m (Wairangi), 45 m (Waitotara).
Ptcm1: 0.5 m (Waitotara).
Ptzm2: 9 m (Wairangi), 10 m (Waitotara).
Ptsm2: 16 m (Wairangi), 60 m (Waitotara).
Ptcm2 (Gully Shellbed, new): 7 m (Okiwa).
Ptzm3: 22 m (Wairangi).
Ptsm3: 33 m (Wairangi).

AGE: early to middle-Mangapanian.

LITHOLOGY: The Pitangi Formation separates the Atene and Moukuku Formations in western Wanganui Basin, and is distinctive for its barren to sparsely fossiliferous nature. All Pitangi Formation siltstone members are relatively sandy compared with other Mangapanian siltstones, and are barren and highly weathered. Both molluscs and foraminifera are largely absent, probably because the high sand content (25-40 % sandstone) within the siltstone accelerates surface weathering, carbonate dissolution and oxidisation. The exception is *Ptzm3* between the Gully and Otere Shellbeds at Okiwa Trig, which has the lowest sand content of the Pitangi Formation siltstone, and is freshly exposed on an actively eroding escarpment beneath Okiwa. The sandstone beds are yellow-brown micaceous and sparsely fossiliferous. Generally, the sandstone is massive, with the exception of *Ptsm1* at Wairangi and *Ptsm2* at Waitotara, both of which are horizontally interbedded with siltstone (~ 0.1 m each layer). A thin, inaccessible shellbed with abundant *Crassostrea* occurs within the lower part of *Ptm1* at R22/642575 in a large road cutting in Waitotara valley. It cannot be correlated with other shellbeds within the formation and is not named. Similarly, no correlative has been located for the thin, poorly developed shellbed (*Ptcm1*) separating *Ptsm1* and *Ptzm2*, at R22/622563 in a small roadside cutting in Waitotara valley. Its stratigraphic position above sandstone and beneath siltstone suggests that it will be more widespread but to date it has not been located elsewhere. Molluscs from this shellbed include *Amalda oraria, Chlamys* and immature *Ostrea.* The Gully Shellbed Member (new, *Ptcm2*) is the most significant shellbed within the Pitangi Formation, and is the only one fully developed at Okiwa Trig. There, the shellbed has two parts, separated by 6.5 m of siltstone. The basal part is a 0.5 m-thick layer of highly weathered, reworked, unidentifiable small bivalves within a sandstone matrix, unconformably overlying sandstone (*Ptsm2*). The upper part of the shellbed is a 0.3 m thick *in situ* layer of *Crassostrea* and *Ostrea* within a siltstone matrix.

A 22 m-thick siltstone bed (*Ptzm3*) at Wairangi (R21/838621) contains *Amalda* and *Gari* (field identifications) at its base and is tentatively correlated with the Gully Shellbed. The top of the Pitangi Formation is only unconformable in the Kauarapaoa, Wanganui, and Whangaehu sections. Correlation of the Pitangi Formation between sections is not simple, as forest cover and poor exposure together with fault offsets within the Nukumaru Fault Zone, and an oblique strike exposure within the Waitotara valley complicates mapping of the stratigraphy.

DEPOSITIONAL ENVIRONMENT: The sandstone to siltstone cycles evident in the Pitangi Formation (Figure 3.1), are interpreted as individual sedimentary sequences. While very few or no molluscs useful for depth analysis have been collected from the formation, the pattern of facies repetition is very similar to that displayed in the overlying and underlying sedimentary sequences. The lack of molluscs is attributed to a combination of turbidity with high rates of sediment accumulation. The two *Crassostrea* horizons within the formation probably therefore represent localised areas of low sediment accumulation, around which sediment was bypassed to the basin depocentre.

MOUKUKU FORMATION.

NAME: The Moukuku Formation was proposed by McIntyre & Kamp (1998) as the uppermost formation of the Paparangi Subgroup. It includes all strata between the Pitangi Formation and the base of the Whauteihi Formation (Wilkies Shellbed). The name is derived from Moukuku (a hill near Te Rimu, Wanganui River), and the formation remains unchanged from its original definition. (Maori: Mou = you, kuku = clamp / clench).

TYPE SECTION AND DISTRIBUTION: As described by McIntyre & Kamp (1998), the type section for the Moukuku Formation is the roadside and riverbank between the Whauteihi Stream mouth and the Wilkies Shellbed at Te Rimu in the Wanganui River valley. The formation occurs within most sections containing Mangapanian strata, variably exposed beneath the bluff-forming Wilkies Shellbed (Okiwa Subgroup). In the Kauarapaoa valley, the formation crops out on the roadside, but continuous exposure exists between sites 22 to 23 (R22/902592) where the Otere Tephra (new) is exposed immediately above the Otere Shellbed, the only known locality where the tephra is exposed in the basin. At Wairangi, exposure is generally poor, the formation cropping out near site 21 (R21/618839). At Paparangi, only part of the formation is exposed below site 13 (R21/785640), with faulting and vegetation obscuring both the upper and lower parts, as well as obscuring stratigraphic relationships with other formations. The Moukuku Formation is well exposed in the gully escarpment on the northwestern face of Okiwa Trig between sites 6 and 7, where it conformably overlies the Pitangi Formation. It was not identified west of this locality. At Parihauhau, the upper part of the formation is exposed on the roadside above Parihauhau School, from the second hairpin bend upsection to the Wilkies Shellbed (site 73, S21/030617), with the lower part of the formation not exposed. The most eastward expression of the Moukuku Formation is in the Whangaehu River valley near Mangamahu between sites 55 and 56 (S22/126546).

THICKNESS: (Total): 57 m (Whangaehu), > 30 m (Parihauhau), 38.5 m (Wanganui), 29 m (Kauarapaoa), 26.5 m (Wairangi), > 34 m (Paparangi), 40 m (Okiwa).

Mocml (Otere Shellbed): 11 m (Whangaehu), 1 m (Wanganui), 2 m (Kauarapaoa), 3.5 m (Okiwa).
Otere Tephra: 0.3 m (Kauarapaoa).

Mozml: 29 m (Whangaehu), 21 m (Wanganui), 12 m (Kauarapaoa), 20 m (Wairangi), 16 m (Paparangi), 34 m (Okiwa).

Mosml (Makokako Sandstone) 17 m (Whangaehu), > 27 m (Parihauhau), 16.5 m (Wanganui), 15 m (Kauarapaoa), 6.5 m (Wairangi), 18 m (Paparangi), 6 m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: Four members comprise the Moukuku Formation: Otere Shellbed, Otere Tephra, an unnamed siltstone bed, and the Makokako Sandstone. The Otere Shellbed and Makokako Sandstone have sufficient internal detail and regional extent to warrant separate descriptions (see below). The unnamed siltstone bed is a typical blue-grey, sparsely fossiliferous Wanganui Basin Pliocene siltstone, with insignificant variation in its character between all studied sections. The Otere Tephra is a moderately cemented, fine-grained, white, massive, pumiceous tephra, 0.3 m thick, conformably overlying the Otere Shellbed. The tephra itself is bioturbated, with trace fossil burrows infilled with siltstone and sandstone contrasting against the pale matrix.

Otere Shellbed Member.

(*Mocml*)

NAME: The Otere Shellbed was first described by McIntyre & Kamp (1998) for the shellbed ~ 40 m beneath the Wilkies Shellbed in Wanganui River valley. The name "Otere" is taken from a site between Moukuku Trig Station and Wanganui River. (Maori: O = of, tere = drift / float).

TYPE LOCALITY: Site 36 (S22/959575), on disused track on the south side of Whauteihi Stream, about 50 m upstream of a bridge on the true left bank.

DISTRIBUTION: The easternmost occurrence of the Otere Shellbed is in Whangaehu valley at site 55 (S22/126546), where it unconformably overlies Pitangi Sandstone in a large bluff above the Whangaehu River at Omahanui. The shellbed is poorly exposed in the Wanganui River valley, cropping out only at the type locality. The best exposure of the shellbed is in Kauarapaoa valley, where it crops out for about 100 m along strike at site 22 (R22/902592), but recently planted pine trees will conceal this site in the near future. Fleming (1953) collected fossils from R21/898628 (GS 4221) and R21/896625 (GS 4222).

Both of these localities are now in dense forest, but mapping and faunal assemblages strongly indicate that this unit is the Otere Shellbed. The Otere Shellbed does not crop out at Wairangi, with its likely position covered by vegetated slump debris. However, the position of the shellbed within the stratigraphy can be accurately estimated by textural patterns through this part of the succession. At Okiwa, the shellbed is not present.

AGE: middle-Mangapanian.

LITHOLOGY: The Otere Shellbed varies dramatically in character across the basin, despite being observed in only three sections. The easternmost occurrence in Whangaehu valley comprises casts of *Ruditapes* and *Dosinia* within four thin sandstone beds, interbedded with sandy siltstone. The unit is highly weathered, with very little remnant carbonate. Each of the four sandstone horizons have disconformable bases, and grade normally upward into siltstone. At Parikino, the shellbed is unconformable with the Pitangi Sandstone, and has two parts. The lower 0.3 m of the shellbed is dominated by well-preserved *Purpurocardia* within a sandstone matrix, which grades upward into a 0.5 m - thick sandy siltstone coquina in which *Ostrea* and *Chlamys* are dominant. In Kauarapaoa valley the shellbed reaches its fullest development. Here a 2 m - thick shellbed unconformably overlies Pitangi Sandstone, with abundant *Purpurocardia* and *Patro* dominating the faunal assemblage in the lower part, with the matrix fining upward from sandstone to siltstone in the upper part, in which *Crepidula* and *Chlamys* are dominant. Most taxa are closely packed disarticulated and current-bedded in the lower part, with preservation improving upsection, and *Crepidula* preserved in a convex-upwards, near-*situ* position.

DEPOSITIONAL ENVIRONMENT: The Otere Shellbed was probably deposited in much the same manner as most other Wanganui Basin Pliocene shellbeds, formed on a transgressive shelf during steadily increasing water depth. The unconformable base of the shellbed in the Whangaehu, Wanganui and Kauarapaoa valleys indicates closer proximity to a paleoshoreline in the central part of the basin, meaning that the shellbed was probably deposited on a shelf that deepened both eastward and westward from these localities. This is supported by the occurrence of *Ruditapes* and *Dosinia* at its easternmost occurrence at Whangaehu valley, and by its deepening eastward into Mangaweka Mudstone. In the west, while the Otere Shellbed is not present, the conformable base of the formation indicates a greater depth of deposition compared with the Wanganui and Kauarapaoa valley equivalents.

Makokako Sandstone Member.

(*Mosml*)

NAME: The name "Makokako Sandstone" was first applied by Fleming (1953) for the fossiliferous sandstone bed underlying the Wilkies Shellbed in the headwaters of the Makokako Stream, a tributary of the Waitotara River. Some of the paleontological lists given in Fleming (1953) for the Makokako Sandstone are in fact from the Otere Shellbed. (Maori: Ma = white, kokako = NZ wattled crow *Callaeas cinerea*).

TYPE LOCALITY AND DISTRIBUTION: Beneath Kuranui Trig at R22/674574 (site GS 4244 of Fleming, 1953). However, faunal lists from this site suggest a closer affinity to a shellbed, possibly the Gully Shellbed. Desipte this, the type locality is retained, and is applied to sandstone above the shellbed at this site. The Makokako Sandstone is well exposed across most of the basin in bluffs beneath the Wilkies Shellbed, cropping out in all major sections between the easternmost expressions in Whangaehu valley to Okiwa Trig in the west. One notable site is site 37 (S22/960575), where it crops out beside the Wanganui River Road.

AGE: middle-Mangapanian.

LITHOLOGY: The Makokako Sandstone is a typical poorly cemented, yellow-brown micaceous Wanganui Basin sandstone bed, but tends to be more fossiliferous than other Mangapanian sandstone units. In Whangaehu valley it is however barren and massive, grading upwards from silty sandstone to well sorted fine sandstone. It is conformably overlain by the Wilkies Shellbed. At Parihauhau a thin siltstone occurs above the main part of the sandstone and beneath the conformable contact with the Wilkies Shellbed. This pattern is repeated in Wanganui valley, with a 1 m thick siltstone overlying the main sandstone. Foraminifera within this siltstone part includes common *Elphidium charlottense, Notorotalia finlayi, Virgulposis wanganuiensis* and *Zeaflorius parri*. The Makokako Sandstone is particularly fossiliferous here, with thin horizons of reworked and disarticulated shallow-water taxa (*Gari, Dosinia, Divaricella* and rare *Phialopecten*) occurring in the lower part of the sandstone, and rare *in situ Atrina* found throughout. The sandstone is also fossiliferous in Kauarapaoa valley, with rare, scattered *Divaricella* and

Dosina common in the relatively fine-grained lower parts, coarsening upsection into well-sorted fine sandstone with very little silt content in the upper part, which is unconformable with the overlying Wilkies Shellbed. At Wairangi, the Makokako Sandstone is relatively thin, poorly exposed, and has the thin siltstone horizon above the main sandstone occurs in some other sections. The unit thickens westward to Paparangi, where it crops out on the roadside as a poorly cemented, well sorted, loose micaceous fine sandstone, unconformably overlain by the Wilkies Shellbed. A thin horizon of shells occurs near the base of the sandstone, containing *in situ Pratulum* and *Barnea.* At Okiwa, the sandstone is thin, blue-grey, poorly cemented, and barren. There, the upper 3 m of the sandstone is horizontally bedded, with subtle (0.1 - 0.5 m thick) alternations between siltstone and sandstone.

DEPOSITIONAL ENVIRONMENT: The Makokako Sandstone is a typical inner-shelf to shoreface Wanganui Basin sandstone, shallowing upward to a shoreface to intertidal deposit. The shell horizons within the sandstone are clearly reworked, and probably storm-emplaced. The occurrence of *Gari, Divaricella* and *Dosinia* indicates that the Makokako Sandstone was probably mostly deposited on an open marine inner shelf, much like that immediately off the present coastline of the Wanganui Bight.

OKIWA SUBGROUP.

(emended)

NAME: The Okiwa Group was established by Fleming (1953), for the fossiliferous shellbeds, siltstone and sandstone stratigraphically intermediate between the Wilkies Shellbed and Ohingaiti Sandstone. The name "Okiwa" derives from Okiwa Trig Station (R22/716597), where the lower part of the subgroup is typically exposed. (A large circular aircraft navigation station now exists at the top of the flat-topped peak). Fleming (1953) partitioned the Okiwa Subgroup into a lower and an upper part, with the base of the Hautawa Shellbed being the intervening horizon. However, the establishment of the Taihape Group (Kamp *et al.* in prep), which extends up to the base of the Hautawa Shellbed, means that the upper Okiwa Group is best renamed. Furthermore, the base of the Okiwa Subgroup was relocated to the base of the Wilkies Shellbed by McIntyre & Kamp (1998) because it forms a distinctive, extensive, mappable horizon, more suitable for a major stratigraphic datum than the top of the Wilkies Shellbed, as originally proposed by Fleming (1953). Thus, the Okiwa Subgroup is now applied to all strata between the base of the Wilkies Shellbed and the base of the Hautawa Shellbed. (Maori: O = of, kiwa = vault).

TYPE LOCALITY AND DISTRIBUTION: For different parts of the Okiwa Subgroup, Fleming (1953) proposed a number of type localities. Emendations of this Group proposed by McIntyre & Kamp (1998) and in this study allow one section, the escarpment at Okiwa Trig, to be the type section of the Subgroup. The Okiwa Subgroup is continously exposed in a large gully at this locality. However, the Subgroup is not complete there, as much rock beneath the Kuranui Limestone and Mangamahu Shellbed present to the east is missing in unconformities at Okiwa. The Subgroup is generally well exposed across the basin, most outcrops being north-facing escarpments capped by resistant shellbeds and limestone. East of Okiwa Trig, the Subgroup is near-continuously exposed on Rangitatau East road below Paparangi Peak at Paparangi (R21/773631), poorly exposed below Kaihokahoka Peak at Wairangi (R21/834611), and on a track cutting leading down into Kai-iwi valley from the track encircling Kaihokahoka Peak. In Kauarapaoa valley, the Subgroup is well exposed in several localities in valley walls above Kauarapaoa Stream, the best sections being a clear face on the south side of a tributary valley at S22/903598, and on a farm track at S22/ 907567, where the upper part of the subgroup is well exposed. In Wanganui valley the subgroup is well exposed in the Te Rimu cliffs above the roadside at S22/955572, poorly exposed on the eastern face of the hillside at S22/963570, and below the roadside near Parikino School, where the upper part is well exposed (S22/940544). The Okiwa Subgroup is moderately well exposed in the Parihauhau Road section, with the lower part cropping out on the roadside as the road climbs up to and follows along the Upokonui-Makotuku watershed. In Whangaehu valley, exposure of the subgroup is variable, and it crops out in several localities. The base of the subgroup occurs at the northern end of large roadside bluffs at S22/134541, the middle part in a cliff on the southern end of a low terrace at S22/ 127536 and on Creek Road near a bridge at S22/154529, and the upper part in riverside bluffs at S22/117529, beneath the prominent Hautawa Shellbed. In Turakina valley the Okiwa Subgroup is well exposed in Otairi Gorge beneath the Hautawa Shellbed at S22/ 228500 and in river bluffs crossing the Turakina River at the bottom of the gorge. The middle to lower part of the subgroup crops out above the roadside about 1.5 km south of Majuba at S22/218528, with the base of the formation represented by a transition from Mangaweka Mudstone to Te Rimu Sandstone at S22/228532. East of Turakina, the Okiwa Subgroup changes character dramatically, becoming less fossiliferous while retaining the siltstone-sandstone alternations evident in the western part of Wanganui Basin. It is exposed beneath the Hautawa Shellbed on West and Watershed Roads between Turakina and Rangitikei valleys (T22/33477 and T22/374487 respectively), thinning to a few metres of sandstone 2 m beneath the Hautawa Shellbed in the Rangitikei River at T22/436457 (Naish & Kamp, 1995).

THICKNESS: 7 m (Rangitikei), 185 m (Watershed Rd), 165 m (West Rd), 200 m (Turakina), 203 m (Whangaehu), 202 m (Parihauhau Rd), 210 m (Wanganui), 215 m (Kauarapaoa), 158 m (Wairangi), 163 m (Paparangi), 103 m (Okiwa).

AGE: middle-late Mangapanian.

LITHOLOGY: The Okiwa Subgroup is characterised by repetitive shellbed, siltstone and sandstone lithologies, alternating in a cyclothemic pattern. Several shellbeds form sufficiently distinctive horizons across the basin to allow subdivision of the subgroup into several constituent formations. Compared with the Paparangi Subgroup, Okiwa Subgroup is more fossiliferous with numerous shellbeds, and displays a more distinctive cyclothemic character. Shellbeds range from 0.5-3 m thick, most have an unconformable base, and consist of tightly packed shells grading from aragonitic molluscs in the basal sandstone matrix to calcitic taxa within siltstone in the upper parts. Shellbeds are conformably overlain by massive, poorly cemented, sparsely fossiliferous, blue-grey siltstone 10-30 m thick, which grades upsection into yellow-brown, massive, sparsely fossiliferous, micaceous sandstone that varies in thickness from 2-20 m. Because of the alternating carbonate-siliciclastic facies within the Okiwa Subgroup, it contains the most lithologically variable formations of Wanganui Basin Mangapanian rocks.

CONSTITUENT FORMATIONS: Whauteihi, Whakaihuwaka, and Parikino.

WHAUTEIHI FORMATION.

NAME: The Whauteihi Formation is named after Whauteihi Stream, a tributary of the Wanganui River that enters the river at Te Rimu. Originally proposed by McIntyre & Kamp (1998), the formation applies to all strata between the Moukuku and Whakaihuwaka Formations. (Maori: Whau = native tree *Pseudopanax arboreus* "Five Fingers", tahi = one. A Maori Pa (fortified village) led by the chieftainess Heke-wairangi at this locality was invaded and overrun in the early 1800s by a hostile tribe) (Downes, 1915).

TYPE LOCALITY AND DISTRIBUTION: As originally described by McIntyre & Kamp (1998), the type locality is in the Wanganui River valley, in roadside cliffs at sites 38-39 (S22/954572). The easternmost expression of the formation is in the Turakina valley, where only the Te Rimu Sandstone is present, cropping out between S22/228532 and ~ 300 m west of Majuba at S22/225525, where the upper contact is exposed. In Whangaehu valley, the Whauteihi Formation crops out in a large roadside cutting at site 56 (S22/134541). The Whauteihi Formation crops out on and forms the watershed between the Mangahowhi and Kahakaha Streams, from S21/032614 to S21/033067, where a sharp contact at the top of the Te Rimu Sandstone crops out beside Parihauhau Road. In Kauarapaoa valley, the formation is well exposed in several places, site 23 (R22/902594; site GS 4208 of Fleming, 1953), on the roadside at site 24 (R22/900581) and site 25 (R22/906597) The Wilkies Shellbed is absent at the latter site. The formation caps and forms the watershed between the Kauarapaoa and Mangaiti valleys between the Kauarapaoa and Wairangi sections, with the lower part cropping out at Wairangi Station at site 21 at R21/841617 (GS 4213; Fleming, 1953). Exposure of the formation is good on the Rangitatau East roadside at Paparangi; about 2 km north of Paparangi Peak at site 14 (R21/784637; GS 4209, Fleming, 1953), but much of the formation is missing in an unconformity, which truncates the formation's upper part. This unconformity has truncated most of the formation at Okiwa Trig (site 8, R22/714598), where only 3 m of the formation is preserved at its westernmost expression.

THICKNESS: 22 m (Turakina), 23 m (Whangaehu), 65 m (Parihauhau), 53 m (Wanganui), 49 m (Kauarapaoa), > 10 m (Wairangi), 5.5 m (Paparangi), 3 m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: Three members comprise the Whauteihi Formation: Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone, in ascending stratigraphic order.

Wilkies Shellbed Member.

(Wtcm1)

NAME: Fleming (1953) named the thick *Crassostrea*-dominated shellbed which crops out distinctively across most of the western part of Wanganui Basin the "Wilkies Shellbed", formalising a name for the "Shellbed near the mouth of the Waitotara River, opposite Wilkies Farm" first described by Park (1887), and referred to as such by Laws (1940). Until

McIntyre & Kamp (1998), the Wilkies Shellbed had formational status, but it subsequently has been demoted to a member of the Whauteihi Formation.

TYPE SECTION AND DISTRIBUTION: Fleming (1953) made Wilkies Bluff (a small, isolated embankment on the left bank of the Waitotara River near its mouth) the type section for the Wilkies Shellbed. However, stratigraphic uncertainty, isolation, near-impossible access, lack of section and doubtful correlation with the abnormally thick *Crassostrea*-rich shellbed in inland sections means that the type locality must be re-located elsewhere. Here, we propose a new type locality (Lectostratotype), at Te Rimu in the Wanganui River valley (site 38, S22/954572), following the suggestion of Beu (1969, p.646). Elsewhere in the basin, the Wilkies Shellbed occurs in Whangaehu valley at site 56 (S22/134541) and near Parihauhau School at site 73 (S21/031616). West of Wanganui River valley, the Wilkies Shellbed is particularly well exposed in Kauarapaoa valley at several localities: near a farm track at site 23 (R22/902594; site GS 4208 of Fleming, 1953) on the roadside at R22/902594 and below the road at site 24 (R22/900581). The shellbed crops out more-or-less continuously on the northern face of the Kauarapaoa / Mangaiti watershed to Wairangi Station (site 21, R21/841617; GS 4213 and R21/833622, GS 4211 (Fleming, 1953)). However, gorse and regenerating bush make access to both of these localities difficult. The shellbed reappears on the Rangitatau East roadside near Paparangi (site 14, R21/784637; GS 4209 of Fleming, 1953), and in the large escarpment on the north face of Okiwa Peak at site 8 (R22/714598), where the top of the shellbed seems to be missing in an unconformity. Other localities west of Okiwa described by Fleming (1953) cannot be confirmed as the Wilkies Shellbed, and are quite possibly a different shellbed, other possibilities being the Gully or Mangamahu Shellbeds. This includes the original "Wilkies Shellbed" type section of Fleming (1953).

THICKNESS: 1 m (Whangaehu), 12 m (Parihauhau), 5-15 m (Wanganui), 8 m (Kauarapaoa), 10 m (Wairangi), 3.5 m (Paparangi), 3 m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: The Wilkies Shellbed is mainly comprised of a distinctive lithology, with abundant, abnormal thicknesses of *in situ Crassostrea ingens* within a siltstone matrix. Typically, *Crassostrea* dominates most of the shellbed, especially the upper part. In Wanganui valley and at Parihauhau, the Wilkies Shellbed is composed almost entirely of closely packed *Crassostrea,* together with a small number of *Chlamys* valves, both *in situ* within siltstone matrix. In these sections, the shellbed is conformable with the underlying Makokako Sandstone, with a 1 m-thick concretionary horizon marking the lower contact. In the Wanganui River section, large sandstone lenses several metres in width and thickness occur within the Wilkies Shellbed, containing rare, reworked and disarticulated *Maoricolpus, Amalda, Divaricella, Zenatia* and *Cyclomactra.* In places, horizons of *Crassostrea* extend a few decimetres into the lenses. In the Whangaehu valley section, the Wilkies Shellbed also has a conformable base, but contains no *Crassostrea,* but has a few highly weathered and unidentified bivalves (possibly *Pratulum*) dominating the faunal assemblage. It passes upsection into a fossiliferous siltstone in which rare *Chlamys gemmulata, Patro* and *Atrina* occur. In Kauarapaoa valley, the shellbed has two distinct parts. The lower 0.5 m is a bivalve-dominated sandy coquina with reworked *Pteromyrtea, Limatula, Ostrea, Eumarcia, Maoricolpus* and *Amalda* also common, unconformably overlying the Makokako Sandstone with up to 1 m relief on the contact. Extensive *Ophiomorpha* burrows containing fragments of aragonitic shell material within silty sandstone extend some 1.5 m downward into the Makokako Sandstone from the base of the shellbed. Where the Wilkies Shellbed crops out on the Kauarapaoa-Mangaiti watershed, these burrows are about 0.1 m in width, and extend about 1 m vertically downward into the Makokako Sandstone, infilled with shell material from the lower part of the shellbed. The upper part of the shellbed is the same facies as in the Wanganui River section, with the *Crassostrea*-dominated facies comprising the upper 7.5 m of the shellbed. At Wairangi, the Wilkies Shellbed retains a similar character as its correlative in Kauarapaoa valley, with the lower part thickening to 1 m, comprised mainly of horizontally oriented, reworked, *Gari, Chlamys, Anomia* and *Sigapatella* within sandstone matrix. The upper 9 m is represented by the *Crassostrea* facies characteristic of the Wilkies Shellbed, which in this case contains a sandstone lens, 4 m thick, of similar facies to the sandstone lenses at Te Rimu (Wanganui River), with rare disarticulated and reworked *Divaricella, Purpurocardia, Maoricolpus* and *Crepidula.* At Paparangi, the lower coquina thickens to 2 m, where it unconformably overlies Makokako Sandstone with local relief of 0.5 m on the contact. Macrofossils include closely packed, reworked and unoriented *Ostrea, Phialopecten, Patro, Purpurocardia, Crepidula* and *Neothyris,* before grading upward into the *Crassostrea*-dominated part, which is 1.5 m thick. At Okiwa, the upper and lower parts are both 1.5 m thick, with the lower part unconformable with bedded Makokako Sandstone, and containing common *Barnea, Ostrea, Tawera, Amalda, Maoricolpus* and *Neothyris* within the sandstone matrix. The upper *Crassostrea*-dominated part of the Wilkies Shellbed maintains the same character and facies common to the shellbed within the basin, but there is truncated by an unconformity, which has superimposed the Mangamahu Shellbed on top of the Wilkies Shellbed.

DEPOSITIONAL ENVIRONMENT: The Wilkies Shellbed is interpreted as having formed on a transgressive shoreline, as shown by the progression from shallow-water, shoreface taxa, such as *Eumarcia, Tawera* and *Gari* at the base, grading upsection into the *Crassostrea ingens* oyster biostrome that comprises the upper part of the shellbed in most of the basin. Christe (1973) placed considerable emphasis on the ecology of modern *Crassostrea,* and favoured an estuarine origin for the shellbed based on the modern species *Crassostrea gigas* and *Crassostrea virginica,* which inhabit shallow estuarine lagoons and restricted bays. However, the occurrence of other taxa within the shellbed (e.g. *Chlamys gemmulata, Ostrea chilensis* and brachiopods) indicates a more marine setting on the contemporary inner-mid shelf, a depositional environment favoured by Fleming (1953). Collections made in this study reveal insignificant numbers of conclusively estuarine taxa (one poorly preserved valve of *Xenostrobus* at Okiwa), indicating a marine setting. The mode of formation was probably that of a biostrome, with sufficiently low turbidity and rate of sediment accumulation to enable new spat to grow on existing shells and continue reef-building at a rate greater than the aggradation of the silt that now comprises the matrix. Thus the *Crassostrea* population was able to maintain optimum conditions for its own survival by accumulating rapidly enough to avoid being buried by sediment, to deny an ecological niche for other fauna to establish, and also possibly to maintain a fairly constant and optimum water depth. The sandstone lenses within the shellbed at Te Rimu and Wairangi are interpreted as channels through which shoreface sediments from coastline erosion were reworked basinwards, bypassing the 'reef'. This interpretation is supported by the shallow-water fauna *Divaricella, Zenatia* and *Cyclomactra* within the lenses. Eventually the lenses became choked with sediment and / or migrated to a different channel, allowing *Crassostrea* to colonise over the channel. The absence of *Crassostrea* in the Wilkies Shellbed at Whangaehu is probably due to too great a water depth for the oysters to inhabit.

Cable Siltstone Member.

(Wtzm1)

NAME: The Cable Siltstone was first described and named by Ker (1973) in the Wanganui River valley at Te Rimu, where a cableway extends across the Wanganui River. Ker (1973) made the Cable Siltstone a member of the Wilkies Shellbed Formation. Subsequently, both the Wilkies Shellbed and Cable Siltstone have been made members of the Whauteihi Formation. Curiously, the existence of this siltstone was not acknowledged by Fleming (1953), despite describing both the Wilkies Shellbed beneath it and the Te Rimu Sandstone above it in his study.

TYPE LOCALITY AND DISTRBUTION: The original type locality of the Cable Siltstone (Ker, 1973) is retained here at Te Rimu, Wanganui River valley, site 39 (S22/954572) at the base of a large bluff on the left bank of the Wanganui River. The siltstone is easily distinguished from other siltstone beds in the Okiwa Subgroup by its proximity to the Wilkies Shellbed, except when the Wilkies Shellbed is cut out by unconformity development in the westernmost part of the basin.

THICKNESS: 14 m (Whangaehu), 51 m (Parihauhau), 28 m (Wanganui), 10 m (Kauarapaoa), 2 m (Paparangi).

AGE: middle-Mangapanian.

LITHOLOGY: Like most Okiwa Subgroup siltstone units, the Cable Siltstone exhibits a remarkably constant character across the basin, as a slightly cemented, sparsely fossiliferous, massive blue-grey siltstone conformably overlying the Wilkies Shellbed, and coarsening upward gradationally into the Te Rimu Sandstone. Rare *in situ Atrina* and *Chlamys gemmulata, Amalda novaezelandiae* and *Ostrea* occur throughout the member in most sections. To the east of Whangaehu valley, the Cable Siltstone grades into Mangaweka Mudstone. At Paparangi, an angular unconformity at the base of the Mangamahu Shellbed has truncated all but 2 m of the Cable Siltstone. All of the siltstone is missing in the unconformity at Okiwa, and probably further to the west.

DEPOSITIONAL ENVIRONMENT: The Cable Siltstone accumulated in quiet, inner-middle shelf conditions, based on the occurrence of *Atrina* and *Amalda novaezelandiae,* the fine-grained texture of the unit, and a lack of bedding features.

Te Rimu Sandstone Member.

(Wtsm1)

NAME: The Te Rimu Sandstone was named by Fleming (1953), based on its occurrence at Te Rimu in Wanganui River valley, where it is typically exposed. This locality also includes the type Wilkes Shellbed and Cable Siltstone, with all three units well exposed on the Wanganui River roadside. Fleming (1953) made the sandstone a formation, but in this study it is demoted to a member of the Whauteihi Formation. Feldmeyer *et al.* (1943) and Fleming (1953) correlated this sandstone bed with the Mangarere Sandstone in the Rangitikei River valley, a correlation that this study has demonstrated to be unsupportable. Here, the Te Rimu Sandstone applies to the sandstone conformably overlying the Cable Siltstone. (Maori: Te = the, Rimu = native podocarp *Dacrydium cupressinum*).

TYPE LOCALITY AND DISTRIBUTION: The type locality of the Te Rimu Sandstone is at Te Rimu, Wanganui River valley (site 39, S22/954572). There, the sandstone is well exposed a few metres above road level, and the nature of and accessibility to the unit varies greatly depending on the state of the unstable and constantly eroding section. Within the Wanganui River valley, the top of the unit is also exposed at Whakaihuwaka at site 40 (S22/943574; GS 4214 of Fleming, 1953). In Turakina valley, it is well exposed at Majuba (S22/227524) where it conformably overlies Mangaweka Mudstone. In Whangaehu valley, it is well exposed on the roadside at site 57 (S22/134539), on the Parihauhau Road roadside at S21/033067. West of Wanganui River, the Te Rimu Sandstone is well exposed in Kauarapaoa valley at site 25 (R22/906597) and on the roadside just south of some houses at S22/902575, where the upper contact is exposed. The Te Rimu Sandstone was not observed west of Kauarapaoa valley, being covered by vegetation at Wairangi, and missing from the rocks in both the Paparangi and Okiwa sections, truncated by the angular unconformity at the base of the Mangamahu Shellbed.

THICKNESS: 22 m (Turakina), 8 m (Whangaehu), 6 m (Parihauhau), 20 m (Wanganui), 10 m (Kauarapaoa).

AGE: middle-Mangapanian.

LITHOLOGY: The Te Rimu Sandstone is a typical slightly cemented, sparsely fossiliferous, bioturbated, micaceous, yellow-brown fine sandstone, of much the same facies as most other Wanganui Basin Mangapanian sandstone beds. In all sections, it is conformable with the underlying Cable Siltstone, with the upper surface overlain unconformably by the Mangamahu Shellbed. The exception is in the Turakina valley, where it conformably overlies the Mangaweka Mudstone, and while the upper surface of the sandstone is unconformable, the Mangamahu Shellbed is not present. In the Whangaehu valley and Parihauhau Road sections, it is a massive, barren, silty sandstone, overlain by the Mangamahu Shellbed in the Whangaehu valley, and by a coarsely alternating sandy siltstone-silty sandstone unit on the Parihauhau Road roadside. At the type section at Te Rimu (Wanganui valley), the Te Rimu Sandstone is horizontally bedded (0.1-1 m), with a 0.1 m-thick layer of shells occurring at Whakaihuwaka, containing reworked and disarticulated *Chlamys, Divaricella, Pteromyrtea, Bassina, Gari, Ruditapes* and *Amalda.* A foraminiferal census from this locality contains common *Elphidium charlottense, Elphidium* aff. *gibsoni, Notorotalia finlayi, Virgulopsis wanganuiensis* and *Discorbis* spp. (McIntyre, 1997). In Kauarapaoa valley, the sandstone is massive and barren, with the base rapidly transitional from siltstone to sandstone over a distance of ~ 1 m. The upper 0.5 m of the sandstone at the roadside site here contains flaser beds, which are penetrated by *Ophiomorpha* borrows extending downward from the base of the Mangamahu Shellbed.

DEPOSITIONAL ENVIRONMENT: The Te Rimu Sandstone is interpreted as having accumulated in an inner shelf, moderate energy environment, as shown by the presence of shallow-water molluscs such as *Divaricella, Gari, Bassina* and *Ruditapes,* together with the shallow-water indicator benthic foraminiferal genera *Virgulopsis, Elphidium* and *Notorotalia.* While the molluscs are obviously reworked, the coarse texture of the sandstone and the horizontal bedding at Te Rimu support an inner-shelf to shoreface depositional environment. The flaser bedding marking the top of the sandstone in the Kauarapaoa valley is consistent with deposits emplaced by dilute traction currents in a shallow, restricted, marginal shallow marine environment, probably above normal wave base.

WHAKAIHUWAKA FORMATION.

(emended)

NAME: All strata between the top of the Te Rimu Sandstone (Whauteihi Formation) and the base of the shellbed at the base of the Tirotiro Formation were assigned by McIntyre & Kamp (1998) to the Whakaihuwaka Formation . During fieldwork for this study, the Tirotiro Formation has proved not to be mappable across the basin, and therefore is included here into the Whakaihuwaka Formation. The name "Tirotiro" has been retained however, and is now applied to the shellbed member in the middle of the Whakaihuwaka Formation. The name "Whakaihuwaka" comes from the locality at a bend in the Wanganui River, about 1 km west of Te Rimu (S22/944576). (Maori: Whaka = in the direction of, ihu = nose, waka = canoe. Historically the name Whakauruawaka is used for this locality, where Whakau = establish, rua = two, waka = canoe).

TYPE LOCALITY AND DISTRIBUTION: The type locality of the Whakaihuwaka Formation remains at Te Rimu, halfway up the large bluff above the roadside between sites 39 and 41 (S22/954572 to S22/956572). Part of the formation also crops out c. 600 m south of Whakaihuwaka on the roadside at S22/939658. The Whakaihuwaka Formation represents the lowermost complete formation of the Okiwa Subgroup in Turakina valley, where two barren alternations between sandstone and siltstone occur between Majuba (S22/227524) and the base the Te Rama Shellbed in the lower part of a large bluff above the roadside at Site 67 (S22/222514). In the Whangaehu valley section, the formation crops out on the roadside at site 57 (S22/134539), and in a bluff at the southern end of a low terrace on the left bank of the Whangaehu River at site 58 (S22/126537). The formation crops out on the Parihauhau Road roadside on the Makotuku-Kahakaha watershed between S22/033607 and S22/029592. In Kauarapaoa valley it is exposed on the north face of an escarpment above sites 26 (S22/912598) and 29 (S22/913598), on the roadside between S22/902575 and site 28 (S22/904568), with the top of the formation exposed just below site 30 (S22/906563) where the base of the Te Rama Shellbed marks the top of the formation. The formation is not well exposed at Wairangi, but the upper part crops out in a cutting on a track leading down to the Kai-iwi valley from Kaihokahoka Peak. At Paparangi, the Whakaihuwaka Formation is near-continuously exposed beside Rangitatau East Road between site 15 (R21/784637) and site 17 (R21/773535). The formation is also well exposed in the Okiwa escarpment between site 9 (R22/714598) and site 10 (R22/714597), with the upper contact of the formation also exposed at site 11 (R22/709585) below the Te Rama Shellbed.

THICKNESS: 71 m (Turakina), 84.5 m (Whangaehu), 60 m (Parihauhau), 47.5 m (Wanganui), 75 m (Kauarapaoa), > 11 m (Wairangi), 75 m (Paparangi), 58 m (Okiwa).

Wkcm1 (Mangamahu Shellbed): 1.5 m (Whangaehu), 6 m (Parihauhau), 0 m (Wanganui), 1.3-3 m (Kauarapaoa), 5.5 m (Paparangi), 1 m (Okiwa).
Wkzm1: 4 m (Turakina), 48 m (Whangaehu), 22 m (Parihauhau), 18 m (Wanganui), 18 m (Kauarapaoa), 43 m (Paparangi),
Wksm1: > 13m (Turakina), 0 m (Whangaehu), 16 m (Parihauhau), 13 m (Wanganui), 7 m (Kauarapaoa), 0 m (Paparangi), 0 m (Okiwa).
Wkcm2 (Tirotiro Shellbed): 0.2 m (Whangaehu), 6 m (Parihauhau), 1.5 m (Wanganui), 1.8 + 1.5 m (Kauarapaoa), 0 m (Paparangi), 3m (Okiwa).
Wkzm2: 7 m (Turakina), 35 m (Whangaehu), 10 m (Parihauhau), 6 m (Wanganui), 27 m (Kauarapaoa), 25 m (Paparangi), 28 m (Okiwa).
Wksm2: 47 m (Turakina), 5 m (Whangaehu), 5 m (Parihauhau), 9 m (Wanganui), 8 m (Kauarapaoa), > 11 m (Wairangi), 0 m (Paparangi), 0 m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: The Whakaihuwaka Formation contains two repetitive shellbed - siltstone - sandstone sequences in ascending stratigraphic order. The formation is notable for its siltstone content, siltstone comprising ~ 70 % of the formation. The base of the formation is marked by the Mangamahu Shellbed, which is conformably overlain by siltstone, and in turn overlain by sandstone in some sections. The Tirotiro Shellbed marks the base of the upper half of the formation, with the siliciclastic material above the shellbed grading from siltstone to sandstone in the manner common to most Wanganui Basin cyclic sequences. Siltstone beds within the formation are much the same as those in other Okiwa Subgroup formations, being slightly cemented, barren to sparsely fossiliferous, massive, bioturbated, and blue-grey in colour. A foraminiferal census from *Wkzm1* at Te Rimu reveals common *Bulimina* aff. *elongata, Cassidulina neocarinata, Elphiduim charlottensis, Nonionella flemingi,* and *Notorotalia finlayi* (McIntyre, 1997). Sandstone units are also typical of those occurring in the Okiwa Subgroup, ranging from loose to slightly cemented, barren to sparsely fossiliferous, yellow-brown and micaceous. Bedding is rare, although in the

Parihauhau Road section *Wksm1* displays 0.1-0.2 m thick tabular bedding that becomes more developed near the top of the unit. The Whakaihuwaka Formation contains no sandstone beds west of Kauarapaoa / Wairangi.

Mangamahu Shellbed Member.

(new)

NAME: The name "Mangamahu Shellbed" is proposed for a previously unrecognised shellbed that crops out conspicuously on the Whangaehu valley roadside about 3.5 km north of Mangamahu settlement, at road level at the base of a large bluff (site 57, S22/134539). This name is not to be confused with the "Mangamahu Concretionary Horizon" of Feldmeyer *et al.* (1943) and Fleming (1953), a unit not satisfactorily located during fieldwork for this study, and thus not acknowledged. (Maori: Manga = creek, mahu = steamy).

TYPE LOCALITY AND DISTRIBUTION: The type locality of the Mangamahu Shellbed is on the Whangaehu valley roadside 3.5 km north of Mangamahu, at site 57, S22/134539. The Mangamahu Shellbed is not present in Turakina valley, where a siltstone bed (*Wkzm2*) unconformably overlies sandstone (*Wtsm1*) at S22/225525 in the expected stratigraphic position of the shellbed. At Parihauhau, the shellbed is not present, but its stratigraphic position is represented by a 6 m-thick unit that alternates twice between silty sandstone and sandy siltstone at S22/902575. In Wanganui valley, the shellbed is very poorly developed, and occurs at the base of a siltstone bed (*Wkzm1*) above the roadside at Te Rimu. The shellbed crops out in several localities in Kauarapaoa valley, on the roadside just south of some houses at S22/902575, and at site 25 (R22/906597). The shellbed does not crop out at Wairangi, as it is hidden in regenerating forest cover. At Paparangi, the Mangamahu Shellbed crops out beside Rangitatau East Road at site 15 (R21/784637; GS 4210 of Fleming (1953)), where it unconformably overlies the Cable Siltstone. At Okiwa, the shellbed is directly and unconformably superimposed on the Wilkies Shellbed (site 9, R22/714598), but a fault at this locality conceals the top of the Mangamahu Shellbed.

THICKNESS: 1.5 m (Whangaehu), 6 m (Parihauhau), 0 m (Wanganui), 1.3-3 m (Kauarapaoa), 5.5 m (Paparangi), 1 m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: The Mangamahu Shellbed exhibits substantial variations in faunal assemblage, lithology and thickness across the basin. However, in all localities where it was observed to crop out the base of the shellbed is unconformable, a feature that becomes more noticeable in the western part of the basin, where it progressively truncates the Whauteihi Formation at a very low angle (<< 1°). At its easternmost locality in the Whangaehu valley, the shellbed is very fossiliferous, with reworked and disarticulated *Divaricella, Pteromyrtea, Dosinia, Eumarcia, Amalda oraria, Fellaster* and pebbles in the sandstone matrix of the lower part. The upper part of the shellbed comprises a near-*in situ* coquina with markedly different taxa - *Crassostrea, Ostrea, Maoricolpus, Crepidula, Penion, Splendrillia* and *Antalis* within a sandy siltstone matrix. At Parihauhau, the shellbed is absent from the section, but a crudely bedded (1 - 2 m thick beds), barren, light yellow-brown sandstone in the appropriate stratigraphic position probably represents the remnant matrix of a leached shellbed. This sandstone is unconformable on the Te Rimu sandstone, marked by a sudden transition from massive sandstone (Te Rimu Sandstone) to coarsely bedded sandy siltstone and silty sandstone. The shellbed is very poorly developed in the Wanganui valley at Te Rimu, with only a few thin (< 0.1 m) isolated clumps of *Chlamys* and *Ostrea* occurring in the base of a siltstone bed (*Wkzml*). In Kauarapaoa valley, the Mangamahu Shellbed has two parts, separated by a barren, faintly bedded silty sandstone bed which is 0.7 m thick at site 25, and 1.5 m thick at the roadside locality. At both sites, the lower part of the shellbed is very thin (~ 0.1 m), and contains reworked common *Chlamys, Maoricolpus* and *Amalda oraria.* The upper part is thicker (0.5 m at site 25, 1.5 - 2 m on roadside), and is comprised of *in-situ Crassostrea* and *Ostrea.* At Paparangi, the Mangamahu Shellbed also has two main parts, which are separated by 4 m of well-sorted fine sandstone. The lower part of the shellbed unconformably overlies the Cable Siltstone near the top of the road cutting at site 15 (R21/784637), where it is a 1 m-thick bivalve-dominated coquina, with most fossil material disarticulated and lying horizontally in a sandstone matrix. There, the shellbed is inaccessible, and apart from *Divaricella* in fallen blocks, identification of the fossil content could not be achieved. The upper part occurs in the upper part of the sandstone bed, where a few isolated specimens of *Chlamys gemmulata, Patro undatus, Divaricella huttoniana* and *Amalda oraria* occur. Collection GS 4210 of Fleming (1953) is considered to be from the upper part of the Mangamahu Shellbed at this locality, not the Te Rimu Sandstone as stated in that work. At Okiwa, the shellbed has two distinct parts, which are in direct contact with each other. A distinctive feature of the shellbed in this section is the abundance of *Purpurocardia,* *Crepidula, Patro* and *Neothyris,* which dominate the faunal assemblage in both parts of the shellbed. There, the lower part overlies the Wilkies Shellbed, and contains a diverse, reworked fauna that includes *Maoricardium, Trachycardium,* and *Pteromyrtea* together with the above fauna, passing upsection into a finer-grained, silty shellbed with common *Phialopecten, Limatula* and *Sigapatella* augmenting the dominant faunal assemblage. The upper contact of the shellbed was not observed, being concealed by a normal fault at this locality.

DEPOSITIONAL ENVIRONMENT: The Mangamahu Shellbed is distinctive compared with most other shellbeds in the Okiwa Subgroup in that it directly overlies and marks a major unconformity. The variability of the faunal concentration from barren to extremely fossiliferous is unusual, and possibly reflects localised siliciclastic sediment satiation, turbidity and/or non-deposition during accumulation. Notable localities that demonstrate this include the Parihauhau and Wanganui River sections, as well as the 4 m-thick sandstone bed separating the upper and lower parts of the Mangamahu Shellbed at Paparangi. This is possibly related to the unconformity development, which may have produced large amounts of terrigenous sediment during truncation of the section.

Tirotiro Shellbed Member.

(new)

NAME: The name "Tirotiro Shellbed" is proposed for the uppermost shellbed within the Whakaihuwaka Formation, above the Mangamahu Shellbed. The name "Tirotiro" was originally used for a formation by McIntyre & Kamp (1998), but it has not proved to be mappable outside the Wanganui River valley where it was originally defined. Furthermore, McIntyre & Kamp (1998) miscorrelated what is now the Tirotiro Shellbed in Wanganui valley with the Parihauhau Shellbed at Parihauhau, an anomaly discovered during fieldwork for this study. Thus, the shellbed is named "Tirotiro Shellbed Member" after a hill north of Parikino. (Maori: Tiro = look).

TYPE LOCALITY AND DISTRIBUTION: The type locality of the Tirotiro Shellbed is halfway up the eastern spur of the large bluff at Te Rimu (site 42, S22/957572), in the Wanganui River valley. There, the shellbed is well exposed on a narrow goat track about 20 m north of the spur crest. The shellbed also crops out on the western side of the Wanganui River at S22/942580, on the south side of a ridge spur. The Tirotiro Shellbed is not present in Turakina valley, but is predicted to occur within an unexposed interval of strata. In the Whangaehu River valley, the shellbed is exposed in a cliff face at site 58 (S22/126537), some ~ 35 m above river level. The shellbed does not crop out on the Parihauhau Road roadside, where its likely stratigraphic position is covered by vegetation. In Kauarapaoa valley, the shellbed is well exposed as two shellbeds, with the lower exposed at site 26 (R22/906597) near the top of a large bluff on the left bank of an unnamed tributary of the Kauarapaoa Stream. The upper Tirotiro Shellbed is exposed at four localities: Site 29 (S22/908597), the roadside at site 28 (S22/904568), on the Kauarapaoa Stream bank at site 27 (S22/906564), and a few metres above the lower Tirotiro Shellbed at S22/907569. The Tirotiro Shellbed does not occur at Paparangi, but is instead marked by a decrease in siltstone content within the Whakaihuwaka Formation midway between the Mangamahu and Te Rama Shellbeds. At Okiwa, it crops out in the large escarpment on the northeastern face of Okiwa Peak as a weakly developed shellbed within siltstone at site 10 (R22/714597). Site GS 4234 of Fleming (1953) at R21/724602 is probably from the Tirotiro Shellbed.

THICKNESS: 0.2 m (Whangaehu), 6 m (Parihauhau), 1.5 m (Wanganui), 1.8 m (Kauarapaoa), 0 m (Paparangi), 3m (Okiwa).

AGE: middle-Mangapanian.

LITHOLOGY: The lithology and taxa within the Tirotiro Shellbed vary significantly across the basin, with no typical facies characterising the shellbed. In the Whangaehu valley, the shellbed is poorly developed and contains only one species, with horizontally lying *Atrina* specimens occurring within a 0.2 m-thick tabular concretionary horizon, conformably overlying sandy siltstone (*Wkzm1*). At its type locality at Te Rimu in the Wanganui River valley, the Tirotiro Shellbed crops out as a well-developed coquina, 1.5 m thick, unconformably overlying sandstone (*Wksm1*) with up to 0.3 m of relief on the contact. The lower 0.5 m of the shellbed consists of a densely packed, reworked, bivalve-dominated shellbed with disarticulated specimens of *Bassina, Ostrea, Chlamys, Crassostrea, Eumarcia* and the urchin *Fellaster zelandiae* within a sandstone matrix. The upper 1 m is comprised of well-preserved, *in-situ* fossils, with common *Patro, Ostrea, Atrina, Purpurocardia, Panopea, Amalda oraria* and *Neothyris.* In Kauarapaoa valley, the shellbed also has two parts; the lower is a 0.3 m-thick sandy shell hash containing disarticulated and unoriented bivalves (*Chlamys, Patro, Anomia* and *Zenatia*), together with the gastropods

Maoricolpus and *Amalda*, and the brachiopod *Neothyris*. The base of the shellbed sharply and unconformably overlies sandstone (*Wksm1*), with shell-filled, concreted *Ophiomorpha* burrows extending up to 0.3 m into the sandstone. The matrix of the shellbed grades upward to siltstone at the top of the shellbed, comprised of two thin (0.1 m) horizons of *Patro* and *Atrina*, within siltstone 1 m above the lower coquina. The upper Tirotiro Shellbed in the Kauarapaoa valley also contains a rich faunal assemblage, with reworked, common *Divaricella, Eumarcia, Sigapatella* and *Fellaster* in the 0.5 m-thick sandy matrix which unconformably overlies flaser-bedded sandy siltstone, in turn punctuated by *Ophiomorpha* burrows infilled with sand and broken shell material extending up to 1 m into it. At site 27 beside the Kauarapaoa Stream, small greywacke pebbles up to 10 mm in diameter are abundant within the lower part of the shellbed. Above the lower part of the shellbed, 1 m of strongly bioturbated, barren, silty sandstone separates the lower and upper parts of the shellbed, with the upper part comprised of *in situ Crassostrea, Alcithoe, Chlamys, Patro, Caryocorbula, Zeacolpus, Crepidula,* and *Amalda,* within a silty sandstone matrix. All the aforementioned taxa with the exception of *Crassostrea* and *Alcithoe,* occur in similar quantities in both the upper and lower parts. At Okiwa, the shellbed is very poorly developed, matrix-supported, with well-preserved, scattered specimens of *Trachycardium, Amalda oraria* and *Divaricella* in the lower 1 m overlain by *Atrina, Anomia, Crepidula, Maoricolpus, Penion, Alcithoe* and *Maoricolpus.* The matrix of the shellbed is silty throughout, and it is conformable with the underlying siltstone (*Wkzm1*).

DEPOSITIONAL ENVIRONMENT: The Tirotiro Shellbed is considered to have accumulated during a transgression, which can be demonstrated at its type locality. There, shallow-water taxa such as *Eumarcia, Bassina* and *Fellaster* at its base indicate a high-energy, sandy, nearshore environment, with a deeper depth of deposition for the upper parts of the shellbed inferred from a finer-grained matrix, better faunal preservation, the absence of shoreface restricted fossils and the occurrence of a deeper shelfal faunal assemblage (*Atrina, Ostrea, Amalda oraria* and *Neothyris*). This pattern is repeated at Okiwa, with relatively shallow water fauna (*Divaricella, Trachycardium*) in the lower part compared with the upper part (*Alcithoe, Atrina* and *Penion*).

PARIKINO FORMATION.

NAME: The Parikino Formation was originally erected by McIntyre & Kamp (1998) for all strata between the bases of the Te Rama and Hautawa Shellbeds. The top of the formation represents the end of the Mangapanian Stage. The name "Parikino" is derived from the settlement in the lower reaches of the Wanganui River, which until the late 1970's was misspelt "Parakino", (Fleming, 1953; St John, 1965; Ker, 1973). (Maori: Pari = cliff, kino = evil. The Parikino Pa (fortified village) was attacked and overrun by the hostile Ngati Apa tribe in the early 1800s, and a member of the defeated garrison leapt off the riverbank into the Wanganui River in retreat (a drop of some 20 m), swam across the river and climbed the steep cliff on the western bank. His pursuer, the enemy chief, upon reaching the base of the cliff abandoned the chase, and called up (in Maori) "If it wasn't for this evil cliff, I'd eat you alive", hence the name (Mead, 1977).

TYPE LOCALITY AND DISTRIBUTION: The type locality of the Parikino Formation remains unchanged from the original designation of McIntyre & Kamp (1998), in the Wanganui River valley at site 44 (S22/962572). There, the formation is variably exposed on a hillside, capped by Nukumaruan strata. Elsewhere in the valley, it is exposed above the roadside at S22/956572, on a farm track at S22/959571 (where the Caseley Conglomerate is exposed), near the top of a hill at S22/951571, beside a farm track on the western side of the Wanganui River at S22/948582, and on the riverbank near Parikino School at site 45 (S22/939543). The formation is represented in the Rangitikei River valley as a few metres of sandstone and siltstone beneath the Hautawa Shellbed at T22/436457, and thickens westward into the Watershed Road section where it crops out between T22/377496 and site 71 (T22/371473). The formation is also well exposed in the Porewa valley, on West Road between T22/339479 and T22/334478, where it is separated from the Mangarere Sandstone by a c. 10 m-thick siltstone bed. In the Turakina valley the formation crops out in the vicinity of Otairi, between Site 67 (S22/222514)and S22/233499. In the Whangaehu valley, the base of the formation crops out at the top of a cliff above the Whangaehu River at site 59 (S22/126536), with the lower, middle and upper parts of the formation cropping out intermittently on the Creek Road roadside between site 60 (S22/153528) and S22/145521. Tthe middle to upper parts are well exposed below the Hautawa Shellbed in the cliffs above the Whangaehu River opposite some farm buildings at site 63 (S22/117529). The formation is poorly exposed in the Mangawhero valley, where the upper part crops out beneath the Hautawa Shellbed above the roadside at S22/062537, and an unidentified shellbed crops out on the roadside at S22/066545. In Kauarapaoa valley, the formation is best exposed on a hillside at S22/907564, where it crops out near-continuously beside a farm track. At Wairangi, the Parikino Formation is exposed in cuttings beside a track leading down to the Kai-iwi valley from Kaihokahoka Peak, but is unfossiliferous, due to dissolution of carbonate material. The formation is well exposed at Paparangi, beside Rangitatau East Road between site 17 (R21/773535) and the Junction Road / Rangitatau East Road intersection, (R21/771632), and up Junction Road to R21/763628, where it is unconformably overlain by the Kuranui Limestone. At Okiwa, the formation is considerably thinner, and crops out variably alongside Rangitatau West Road between the base of the Te Rama Shellbed and the Kuranui Limestone, with the middle parts (*Pksm1*) well exposed near the sheep yards at the end of the road.

THICKNESS: 7 m (Rangitikei), 80 m (Watershed Rd), 72 m (West Rd), 97 m (Turakina), 95 m (Whangaehu), 85 m (Parihauhau), 102 m (Wanganui), 92 m (Kauarapaoa), 65 m (Wairangi), 88 m (Paparangi), 45 m (Okiwa).

(*Pkcfm1*) Caseley Conglomerate: 8 m (Wanganui).

(*Pkcm1*) Te Rama Shellbed: 0.5 m (Turakina), 1 m (Whangaehu), 0.5 m (Parihauhau), 1 m (Wanganui), 1.5 m (Kauarapaoa), 1.5 m (Paparangi), 1.3 m (Okiwa).

(*Pkzm1*): 13 m (Turakina), 7 m (Whangaehu), 40 m (Wanganui), 7 m (Kauarapaoa), 13 m (Wairangi), 33 m (Paparangi), 13 m (Okiwa).

(*Pksm1*): 17 m Turakina), 4 m (Whangaehu), 8 m (Parihauhau), 10 m (Wanganui), 4 m (Kauarapaoa), 19 m (Wairangi), 14 m (Paparangi), 12 m (Okiwa).

(*Pkcm2*) Parihauhau Shellbed: 8 m (Turakina), 1.5 m (Whangaehu), 2 m (Parihauhau), 0.5 m (Wanganui), 2.6 m (Kauarapaoa), 0.5 m (Paparangi).

(*Pkzm2*): 19 m (Turakina), 29 m (Whangaehu), 30 m (Parihauhau), 20 m (Wanganui), 51 m (Kauarapaoa), 30 m (Wairangi), 33 m (Paparangi), 18.5 m (Okiwa).

(*Pksm2*): 36 m (Watershed Rd), 33 m (West Rd), 15 m (Turakina), 11 m (Whangaehu), 10 m (Parihauhau), 5 m (Wanganui), 11 m (Kauarapaoa), 1.5 m (Wairangi), 18 m (Paparangi).

(*Pkcm3*) School Shellbed: 0.5 m (Watershed Rd), 0.5 m (West Rd), 1 m (Turakina), 3 m (Whangaehu), 4 m (Parihauhau), 3 m (Wanganui), 2.5-14 m (Kauarapaoa).

(*Pkzm3*): 44 m (Watershed Rd), 46 m (West Rd), 6 m (Turakina), 38 m (Whangaehu), 30 m (Parihauhau), 25 m (Wanganui), 11 m (Kauarapaoa).

(*Pksm3*): 7 m (Rangitikei), 17 m (Turakina).

AGE: late-Mangapanian.

LITHOLOGY: The Parikino Formation is comprised of three cyclothems, which display a typical shellbed-siltstone-sandstone repetitive motif. The formation is thickest in Turakina valley, thinning both eastward and westward of this region. To the east of Turakina valley, the formation passes laterally into Mangaweka Mudstone, while in the west, an angular unconformity at the base of the Kuranui Limestone truncates much of the upper part of the formation. The three siltstone units within the formation are typically slightly cemented, blue-grey in colour and massive, with the exception of *Pkzm2* in the Kauarapaoa valley. This unit is horizontally bedded throughout, with sandstone-siltstone alternations of 0.1 - 0.2 m and flaser beds (2 cm thick) common. Sandstone members within the Parikino Formation are generally similar to other late Pliocene sandstone facies within the basin, being slightly cemented, well sorted, barren to sparsely fossiliferous, yellow-brown micaceous sandstone beds, that conformably overlie siltstone members, and in most sections are unconformably overlain by shellbeds. While bedding structures are rare, at Okiwa Trig sandstone member *Pksm1* displays spectacular low-angle cross-bedding in its upper part. Three promiment shellbeds occur within the formation, the Te Rama, Parihauhau and School Shellbed Members, which are each described below in detail.

Caseley Conglomerate Member.

NAME: In Wanganui valley, the name "Caseley Conglomerate" was applied by McIntyre & Kamp (1998) to a channelised andesite conglomerate, which appears to be incised into the Whakaihuwaka Formation, and is overlain by the Te Rama Shellbed. The name "Caseley" comes from the current landowner of the farm on the Te Rimu promontory.

TYPE SECTION AND DISTRIBUTION: The type section for the conglomerate is at S22/959571, where the base of the unit is scoured into Whakaihuwaka Formation silty sandstone. It also crops out on the western side of the Te Rimu Bluffs in a saddle at S22/951571, and also on the western bank of the Wanganui River at S22/948582. It was not observed outside the Wanganui River valley.

THICKNESS: 8 m (Wanganui).

AGE: late-Mangapanian.

LITHOLOGY: The conglomerate is moderately well cemented and has a red-black appearance in outcrop, due to iron oxide precipitation from the movement of meteoric water through the deposit. Coarse quartzo-feldspathic sands infill intraclast pore spaces between well-rounded andesite cobbles and boulders (up to 0.3 m in diameter), which contain large pyroxene phenocrysts. Unoriented blocks of fossiliferous mudstone occur randomly within the unit, and are probably derived from either the Tirotiro or Te Rama Shellbeds. A thin-section of a typical clast reveals common hypersthene, augite and plagioclase, with rare smal lgrains of opaque minerals.

DEPOSITIONAL ENVIRONMENT: The Caseley Conglomerate is thought to be a non-marine conglomeratic channel fill deposit, formed by subaerial exposure and incision of the contemporary inner shelf during sea-level lowstand conditions immediately prior to the accumulation of the Te Rama Shellbed. The channel itself was possibly subsequently infilled by non-marine conglomerates during the early stages of a transgression as sea-level and thus base level rose, causing the channel to become progressively backfilled, clogged, and eventually flooded by the marine transgression.

Te Rama Shellbed Member.

NAME: Fleming (1953) gave the name "Te Rama Shellbed" to a ~ 1.5 m-thick coquina cropping out "intermittently for 3 miles between Okiwa and Kuranui trig stations, and crops out on the north face of the hill forming Te Rama Trig Station". The name is retained here, as the basal member of the Parikino Formation, downgraded from Fleming's (1953) original "undifferentiated formation of the Okiwa Group". (Maori: Te = the, Rama = light).

TYPE LOCALITY AND DISTRIBUTION: No formal type locality was given by Fleming (1953), so the exposure of the shellbed beside Rangitatau West Road at site 11 (R22/706583; GS 4189, Fleming, 1953) is proposed for the type locality. Elsewhere in this section, the shellbed crops out below Te Rama Peak at R22/702581, and in the Okiwa escarpment at R22/715598. The easternmost exposure of the Te Rama Shellbed is on the Turakina valley roadside at Site 67 (S22/222514) 1 km north of James Road, and it also crops out ~ 100 m above the road in the bluff immediately to the north of this site. In the

Mangamahu Stream section, it is well exposed about 20 m north of the Creek Road bridge at site 60 (S22/153528; GS 4362 of Fleming, 1953), where it crops out on the roadside as a 1 m-thick coquina, unconformably overlying Tirotiro Formation sandstone. A shellbed cropping out at the top of a bluff above a low terrace at site 59 (S22/126536) is considered to be the Te Rama Shellbed, but lack of access precludes definitive identification. The shellbed is not particularly fossiliferous at Parihauhau, where it crops out on the roadside at S22/029592, where several small normal faults displace the shellbed by a few metres to the south. In Wanganui valley, the shellbed is best exposed at Te Rimu, above the Wanganui River Road at site 43 (S22/957572), where it forms a goat track along the eastern end of the base of the sheer face at the top of the bluffs. The shellbed also crops out on the western bank of the Wanganui River at S22/963570, beside a farm track and fence line running down a spur opposite Whakaihuwaka. The Te Rama Shellbed is also well exposed in the Kauarapaoa valley, just below site 30 (S22/906563), where it crops out some 14 m below the Parihauhau Shellbed. At Paparangi, the shellbed is well exposed beside Rangitatau East Road at site 17 (R21/773635).

THICKNESS: 0.5 m (Turakina), 1 m (Whangaehu), 0.5 m (Parihauhau), 1 (Wanganui), 1 m (Kauarapaoa), 1.5 m (Paparangi), 1.3 m (Okiwa).

AGE: late-Mangapanian.

LITHOLOGY: The Te Rama Shellbed is different from other late Mangapanian Shellbeds within Wanganui Basin in containing rare greywacke and quartz pebbles, a feature that assists in correlation of the unit between sections. Sections in which these pebbles occur are the type section at Okiwa. and the Paparangi and Whangaehu River valley sections. At the type locality, the shellbed conformably overlies Tirotiro Formation siltstone, and contains mildly reworked molluscs in the lower 0.5 m, including disarticulated and broken *Dosinia, Anomia* and *Limatula* within the siltstone matrix. This passes upwards into a more fossiliferous and diverse coquina, with common to rare, well-preserved and *in-near situ Phialopecten thomsoni, Patro, Ostrea, Anomia* and *Purpurocardia,* together with brachiopods (*Neothyris*) and branching bryozoans. In Turakina valley, the shellbed is very poorly developed, unconformably overlying sandstone and containing rare molluscs (*Zenatia* and *Anomia*) within a silty sandstone matrix at the base of the shellbed, and with *Atrina, Crassostrea, Maoricolpus* and *Amalda oraria* rare in the upper part. In the Creek Road section, the shellbed sharply and unconformably overlies Tirotiro Formation sandstone, with a sandy shell hash dominated by *Fellaster* in the lower part grading upward into a siltstone-supported coquina in which *in-situ* specimens of *Atrina* and *Crassostrea* are abundant. The shellbed appears to have a similar character in the nearby Whangaehu River locality, but due to inaccessibility, the faunal assemblage can only be derived from fallen boulders at the base of the outcrop. In these boulders, the micromollusc *Myllitella* is abundant, and *Nucula, Chlamys, Patro* and *Amalda* are common, along with rare small (< 5 mm) greywacke pebbles. In the Parihauhau Road section, the base of the shellbed is unconformable, with the shellbed itself being highly weathered and oxidised, and containing casts and poorly preserved specimens of *Chlamys, Crassotrea, Ostrea, Atrina* and barnacles (probably *Austromegabalanus*) within bedded (0.2 m) sandstone. There, two normal faults displace the shellbed by 4 m and 1 m respectively. In the Wanganui River valley, the Te Rama Shellbed has two parts, separated by 0.6 m of fine sandy siltstone. The lower shellbed, 0.2 m thick, is unconformable upon the underlying Whakaihuwaka Formation, and contains well-preserved, disarticulated and reworked bivalves - *Bassina, Eumarcia, Dosinia subrosea, Chlamys, Ostrea* and the urchin *Fellaster.* The upper coquina also contains well-preserved molluscs, with a mixture of articulated and disarticulated *Divaricella, Stiracolpus, Amalda* (2 species), *Ostrea, Chlamys, Gari* and *Dosinia* within a fine sandy siltstone matrix. To the west of Wanganui valley in Kauarapaoa valley, the Te Rama Shellbed unconformably overlies sandstone, as a 1 m-thick, well-cemented shell layer. The lower, 0.5 m-thick part contains poorly preserved, common *Atrina, Ostrea* and *Chlamys* within a low-angle cross-bedded sandstone matrix, with the upper 0.5 m-thick part of the shellbed comprised of a loose, sandy shell hash containing a similar fauna to the lower part, capped by a 0.15 m-thick layer of well-preserved and articulated *Crassostrea* specimens within a sandy siltstone matrix. At Paparangi, the shellbed contains a rich, diverse fossil assemblage in the lower 0.5 m of the unit, which is conformable on the underlying Whakaihuwaka Formation. There, varying abundances of *Phialopecten, Lima, Pteromyrtea, Caryocorbula, Phenatoma, Sigapatella* and *Pleuromeris* occur near the base of the shellbed, passing upwards into a markedly different faunal assemblage in which *Anomia, Ostrea, Taniella, Lamprodomina* and *Alcithoe* occur, with common and abundant *Atrina, Chlamys, Patro, Maoricolpus, Zeacolpus, Crepidula, Amalda oraria* and *Neothyris* occurring throughout the shellbed. Preservation is good, with most fossils being *near* to *in situ.* Pebbles are rare within the shellbed, with the largest (up to 15 mm) in the base of the shellbed. A thin layer of *Atrina* specimens, 0.2 m-thick, occurring in siltstone 0.8 m above the main part of the Te Rama Shellbed was traced almost continuously eastward for some 100 m within the section.

DEPOSITIONAL ENVIRONMENT: The Te Rama Shellbed is considered to have accumulated in much the same manner and paleogeographic conditions as the Tirotiro Shellbed, based on the similarity of the outcrop patterns, architecture and stratigraphic proximity between the two shellbeds. The unconformable base and shallow-water fauna in the shellbed in the Turakina, Creek Road, Whangaehu, Parihauhau, Wanganui River and Kauarapaoa valley sections indicate a closer proximity to a paleoshoreline than those sections both to the east and west of these localities, which presumably occupied a relatively deeper water position on the inner paleoshelf. As with most other Mangapanian shellbeds in Wanganui Basin, the occurrence of successively deeper-water fauna from the base to the top of the shellbed (i.e. *Divaricella, Fellaster, Dosinia* grading up into *Crassostrea, Crepidula, Alcithoe* and *Neothyris*) means that the shellbed accumulated during a transgression, which in this case is considered to have been less than ~ 50 m in amplitude. The occurrence of the small greywacke pebbles within the shellbed is difficult to explain, but is possibly related to a southern source and transport along a shoreline associated with the Patea-Tongapourutu High, or perhaps reflects reworking of alluvial material during the transgression in which the Te Rama Shellbed accumulated.

Parihauhau Shellbed Member.

NAME: Fleming (1953, p128-129) noted "a 10 ft fossiliferous grey muddy sandstone, named the Parihauhau Shellbed, from its conspicuous outcrop on Parihauhau Road below Upokonui Trig Station... lying 250 ft stratigraphically above the Te Rimu Sand". Originally an undifferentiated formation of the Okiwa Group (Fleming, 1953), the Parihauhau Shellbed is demoted here to a member of the Parikino Formation. In the Wanganui River valley, McIntyre & Kamp (1998) miscorrelated the Parihauhau Shellbed with what is now recognised as the Tirotiro Shellbed, an error discovered and rectified in both Kamp & McIntyre (1998) and in this study. (Maori: Pari = cliff, hau = windy).

TYPE LOCALITY AND DISTRIBUTION: The site originally described for the Parihauhau Shellbed on the Parihauhau Road roadside (Site 74, S22/016578; GS 4205, Fleming, 1953) is here formalised as the type locality. The shellbed is also exposed on the roadside at S22/029592, where it crops out approximately 7 m above the Te Rama Shellbed. The shellbed is also well exposed beside the Turakina valley Road at site 69 (S22/230504), and on the riverbank about 100 m downstream from the bridge at this locality (GS 4349 of

Fleming, 1953). A shellbed near the top of the large bluff above the roadside about 1 km north of James Road (site 68, R22/217518) is also thought to be the Parihauhau Shellbed. The shellbed is also well exposed beside Creek Road at site 61 (S22/153528) some 50-60 m north of the bridge over the Mangamahu Stream, and about 11 m above the Te Rama Shellbed. The Parihauhau Shellbed is not well exposed in the Wanganui River valley, cropping out in a small scarp on a grassy hillside at site 44 (S22/962572). In the Kauarapaoa valley, it is exposed in a cutting on a steep farm track winding up the ridge between the Waiehu and Kaiwha Streams at site 30 (S22/906563). The Parihauhau Shellbed does not occur at Wairangi, but crops out at Paparangi about 200 m north of the Rangitatau East / Junction Road intersection in a circular slump scarp above the roadside at site 18 (R21/772632). At Okiwa Trig, the Parihauhau Shellbed is not present, and siltstone overlies burrowed sandstone at the appropriate stratigraphic position.

THICKNESS: 8 m (Turakina), 1.5 m (Whangaehu), 2 m (Parihauhau), 0.5 m (Wanganui), 2.6 m (Kauarapaoa), 0.5 m (Paparangi).

AGE: late-Mangapanian.

LITHOLOGY: The Parihauhau Shellbed is one of the least fossiliferous of the Wanganui Basin Mangapanian shellbeds, being best developed at its type locality on Parihauhau Road, where it forms a 2 m-thick compound shellbed unconformably overlying burrowed, loose sandstone (*Pksml*). There the shellbed is moderately fossiliferous, with dispersed shell material supported within the siliciclastic matrix, which grades from sandstone at the base of the shellbed to siltstone in the upper parts. The fauna grades from mainly *Divaricella, Dosinia subrosea* and *Crepidula* at the base, into a diverse assemblage of well-preserved, *in-situ* taxa, in which *Chlamys, Ostrea, Atrina, Crassostrea, Amalda* and *Patro* are common. In the Turakina valley, the shellbed has two parts, which are separated by a 6.5 m thick massive sandstone bed (containing common *in-situ Atrina)* which grades normally into siltstone. *Eumarcia* dominates the fossil assemblage in the 0.2 m-thick lower shellbed, together with rare *Amalda oraria* and *Dosinia.* The 1.5 m-thick upper part contains a much more diverse fauna, with common *Chlamys, Patro, Ostrea* and rare *Crassostrea, Semicassis, Penion* and *Alcithoe.* The Parihauhau Shellbed is relatively fossiliferous in the Creek Road section, with a diverse faunal assemblage ranging from closely packed to dispersed fossil material in generally well preserved condition. There, the base of the shellbed is a burrowed unconformity, with few isolated specimens of *Divaricella,* *Pleuromeris, Dosinia* and turritellids (*Maoricolpus, Stiracolpus*) within the sandstone matrix comprising the lower part of the shellbed. The matrix fines upwards into siltstone, a transition that is accompanied by an increase in shell concentration and a change in faunal composition, with common, *near-situ Chlamys, Ostrea, Patro, Crepidula, Amalda* and *Antalis,* supplemented by rare *Pratulum, Alcithoe* and *Penion.* At Te Rimu (Wanganui River valley), the Parihauhau Shellbed is typically weakly developed, homogenous, and comprised of loosely packed *Atrina, Chlamys, Ostrea, Dosina, Sigapatella* and *Amalda* within a sandy siltstone matrix unconformably overlying sandstone (*Pksm1*). The shellbed maintains a similar appearance in the Kauarapaoa valley; unconformably overlying sandstone with infilled *Ophiomorpha* burrows extending up to 0.5 m into the sandstone from the unconformity. The shellbed itself is comprised of two parts, both containing loosely packed, moderately diverse fossils within sandy siltstone. Disarticulated *Chlamys, Crepidula* (both common) and rare *Dosinia* specimens occur in the lower part, with *Atrina* and *Crassostrea* common in the upper. *Anomia, Patro, Maoricolpus* and *Neothyris* are common throughout the shellbed, in a generally well-preserved condition. At Paparangi the Parihauhau Shellbed is very weakly developed, occurring as a loosely packed shell concentration at the base of a siltstone bed (*Pkzm2*), which is unconformable on the loose, well-sorted sandstone *Pksm1.* There, rare, disarticulated and reworked specimens of *Dosina, Dosinia, Maoricolpus, Zeacolpus* and common *Chlamys, Anomia, Ostrea, Amalda oraria* and *Neothyris* occur within the main part of the shellbed, within a sandstone matrix. In the lower 0.5 m of the siltstone above the shellbed, dispersed, articulated, *in-situ* specimens of *Atrina, Patro, Pelicaria* and *Alcithoe* occur in varying abundance. At Okiwa Trig, no shellbed occurs in the predicted stratigraphic position, the unconformable and burrowed contact between *Pksm1* and *Pkzm2* being barren.

DEPOSITIONAL ENVIROMENT: Like most other Okiwa Subgroup shellbeds, the Parihauhau Shellbed is interpreted as deposited during a transgression, as shown by the unconformable base, and the occurrence of successively deeper-water molluscs such as *Divaricella* and *Dosinia* at the base, through to *Antalis, Crassostrea* and *Alcithoe* in the upper parts. Thus, the amplitude of the relative sea-level change during transgression is considered to have been about 40 m. The low faunal concentration is probably due to high sediment turbidity during accumulation of the unit, an inference supported by the absence of the shellbed from some sections.

School Shellbed Member.

NAME: The name "School Shellbed" is given here to the youngest Mangapanian Shellbed after its exposure on the left bank of the Wanganui River just south of Parikino School, beneath the Wanganui River Road at site 45 (S22/939543). While the original description of the School Shellbed was by McIntyre & Kamp (1998, p.79), no name was given other than the lithologic code *Pkcm3*, also used here as an alternative to the name "School Shellbed".

TYPE LOCALITY AND DISTRIBUTION: The type locality remains on the riverbank about 100 m south of Parikino School at site 45 (S22/939543). It also crops out poorly on the hillside some 40 m above the Parihauhau Shellbed at site 44 (S22/962572). The easternmost occurrence of the shellbed is in the Watershed Road section at (T22/376489), and in nearby Porewa valley at T22/336478. The shellbed is poorly exposed, poorly developed and poorly accessible in Turakina valley, and crops out in a slip below the roadside about 200 m north of the Otairi Station entrance (S22/231499). The best exposure of the shellbed in the Whangaehu River valley is at site 63 (S22/116529) where it crops out in a large bluff above the Whangaehu River about 40 m above river level. The School Shellbed is also exposed on Creek Road at site 62 (S22/148524). Between the Whangaehu and Wanganui River sections, the School Shellbed was only observed at one locality, on the banks of a steam beneath Parihauhau valley Road at site 50 (S22/984555). A highly weathered shellbed capping a hill at S22/013575 above the Parihauhau Shellbed type locality also probably represents the School Shellbed. The westernmost occurrence of the School Shellbed is in the Kauarapaoa valley, where it crops out a few metres below the Hautawa Shellbed. There it crops out beside the Kauarapaoa Stream at R22/900554 less than 1 m below the Hautawa Shellbed, and can be traced downstream intermittently for several hundred metres. It is also well exposed near a hairpin bend on a farm track at site 31 (S22/908565). The westernmost occurrence of the shellbed is at the top of a hill at R22/ 894576. The School Shellbed does not crop out west of Kauarapaoa valley, as it is truncated at the angular unconformity at the base of the Kuranui Limestone.

THICKNESS: 0.5 m (Watershed Rd), 0.5 m (West Rd), 1 m (Turakina), 3 m (Whangaehu), 4 m (Parihauhau), 3 m (Wanganui), 2.5-14 m (Kauarapaoa).

AGE: late-Mangapanian.

LITHOLOGY: The School Shellbed is easily correlated between sections due to its distinctive thickness of rich fossil material, its stratigraphic proximity to the Hautawa Shellbed, and the concentrations of *Crassostrea* that characterise the upper part of the shellbed, especially in the Wanganui River and Kauarapaoa valley sections. In the Watershed and West Road sections, the shellbed unconformably overlies sandstone (*Pksm2*), as a poorly preserved layer of indeterminate, highly weathered, closely packed, aragonitic bivalves, which are disarticulated and lie horizontally convex-upwards within a loose, fine micaceous yellow sandstone matrix. In the Turakina valley, the base of the School Shellbed is unconformable on the underlying sandstone, is poorly developed, and has two parts. The lower is 0.3 m thick, and contains rare, disarticulated specimens of *Dosinia, Chlamys, Struthiolaria, Ostrea* and *Patro* within a silty sandstone matrix. This passes upwards into the upper part, which is 0.2 m thick, and is comprised of sandy siltstone in which well-preserved specimens of *Crassostrea, Amalda* and *Ostrea* are rare. In all studied sections westward of the Turakina valley, the base of the shellbed is unconformable, and the shellbed itself is composed of two parts. Typically, the lower part is composed of disarticulated and reworked bivalves, with common *Eumarcia* and *Divaricella* within a loose, yellow brown micaceous sandstone matrix. The upper part is comprised of well-preserved epifaunal fossils, with *Crassostrea, Ostrea, Phialopecten* and *Chlamys* dominant within the siltstone matrix. At Mangamahu in the Whangaehu River valley, the two parts of the shellbed (both 0.5 m thick) are separated by 2 m of massive silty sandstone, with both parts highly fossiliferous. The lower part contains common *Divaricella, Pteromyrtea, Eumarcia, Amalda oraria, Crepidula, Fellaster* and rare *Sigapatella* with the fossils being current-bedded, and most bivalves lying convex-upwards within the sandy matrix. Epifaunal molluscs dominate the faunal composition of the upper part, which has relatively lower fossil concentrations compared with the lower. Here, common specimens of *Crassostrea, Chlamys, Patro* and *Ostrea* occur, with the last three in slightly higher concentrations and better state of preservation than in the lower part. At Parihauhau, the two parts of the shellbed are in direct contact, both being 2 m thick. Many fossils are common to the upper and lower parts: *Atrina, Chlamys, Divaricella, Dosinia, Crepidula,* and *Amalda,* which are all common throughout the shellbed, in a variety of preservation states and articulation. The lower part is comprised of reworked and current-bedded fossil mollusc and urchin skeletal material within a sandstone matrix, with the above list supplemented by common *Anomia, Eumarcia* and *Fellaster.* In addition to the fossils throughout the shellbed, the upper part is generally comprised of well preserved, *near-in* *situ* fossils within a sandy siltstone matrix, including common specimens of *Patro, Ostrea, Maoricolpus, Neothyris* and rare *Crassostrea, Pteromyrtea, Austrofusus, Lamprodomina, Alcithoe* and *Comitas.* At Parikino, the shellbed maintains its richly fossiliferous nature, with the lower 1 m of the shellbed containing a high concentration of well preserved, reworked *Eumarcia, Dosinia, Divaricella* and *Pteromyrtea* in a light brown sandstone matrix, grading upward into a 2 m thick siltstone-supported coquina containing common *in situ Atrina, Chlamys, Anomia, Patro, Crassostrea, Ostrea, Amalda,* and rare *Nielo, Tawera* and *Alcithoe.* In the Kauarapaoa valley, the School Shellbed is highly variable in thickness, thickening from 1.5 m at site 31 to 14 m at the westernmost exposure of the shellbed at R22/894576. At site 31, the base of the shellbed is marked by a 2 m-thick sandstone-supported, loosely packed, reworked, bivalve-dominated shellbed, in which common *Anomia, Patro, Divaricella, Dosinia, Amalda, Neothyris* and rare *Tawera, Myadora, Crepidula* and *Fellaster* occur. Conformably overlying this, the upper part is mainly comprised of abundant *Crassostrea* and common *Phialopecten, Chlamys* and *Ostrea.* The other two exposures of the School Shellbed in the Kauarapaoa valley maintain a generally similar faunal content and architecture. The only variable is the thickness of the upper *Crassostrea*-rich part of the shellbed, which is 3 m thick where it crops out on the left bank of the Kauarapaoa stream at R22/900554, and 11 m thick at the top of the hill at R22/894576. Here the shellbed has a remarkably similar appearance to the Wilkies Shellbed, which crops out in the Kauarapaoa Stream banks approximately 200 m stratigraphically below this site.

DEPOSITIONAL ENVIRONMENT: Like most shellbeds in Wanganui Basin, the School Shellbed is inferred to have accumulated by stratigraphic condensation during a period of marine transgression. Observations supporting this premise are the upward fining nature of the terrigenous matrix, and the increase in quality of preservation, articulation and proportion of life position of molluscan skeletal material upwards throughout the shellbed. The unconformable base and well-sorted fine sandstone matrix in the lower parts of the shellbed through into the siltstone matrix and fauna of the upper part show a deepening from nearshore to the outermost parts of the inner shelf, preceding burial by shelf mudstone. In addition to vertical depositional patterns, the School Shellbed displays one of the strongest lateral trends of the late Mangapanian shellbeds. The deepest part of the shellbed is inferred to have lain in the west, as shown by the abnormal thickness of *Crassostrea,* which probably formed a biostrome in much the same manner as in the Wilkies Shellbed. Presumably this *Crassostrea* layer extended much further to the west than its current exposure suggests, and it is possibly responsible for the isolated, reworked and encrusted

Crassostrea that occur sporadically within the (Nukumaruan) Kuranui Limestone. East of Kauarapaoa valley, the *Crassostrea* concentration in the upper shellbed decreases. *Crassostrea* is rare in the Turakina valley section, which is interpreted as a shallowing to the east. This is consistent with the occurrence of a 0.5 m-thick terrigenous unit separating the two parts of the shellbed at that locality, a feature that has been demonstrated to occur in the shoreward part of cross-section profiles of other shellbeds (a shore-connected sediment wedge). Furthermore, the occurrence of only the lower part of the shellbed in the West and Watershed Road sections is consistent with a nearshore, current-bedded shell lag deposit, in which only infaunal taxa occur. The absence of the School Shellbed in the Rangitikei River section means that the paleoshelf probably sloped steeply east of the Watershed Road section.

RANGITIKEI GROUP.
(emended)

Te Punga (1953) originally proposed the name "Rangitikei Group" for strata in the Rangitikei River valley. The name has undergone emendations by Naish & Kamp (1995) and Naish *et al.* (2001). Usage of the group is retained here, following the emendations proposed by Naish *et al.* (2001). For the purposes of this study, the Rangitikei Group refers to all strata between the base of the Hautawa Shellbed and the base of the Waipuna Conglomerate. Since this study is only concerned with the lowermost part of the group, readers are referred to Naish *et al.* (2001) for further details of the middle and upper parts.

WHARIKI FORMATION.

NAME: The name “Whariki Formation” is derived from Whariki Stream, which enters the Wanganui River near Parikino School. It was proposed by McIntyre & Kamp (1998) for the collection of distinctive units occurring at the base of the Wanganui Basin Nukumaruan succession, which include the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone Members. The name is retained in this study in favour of the use of “Tikapu Formation” of Naish & Kamp (1995), which is less applicable to strata in western Wanganui Basin than in the eastern part of the basin, where it was initially erected. Thus, the Whariki Formation applies to all strata between the base of the Hautawa Shellbed and the base of the Tuha Shellbed. (Maori: Whariki = mat, rug).

TYPE LOCALITY AND DISTRIBUTION: The original type locality of the formation at Site 46 (S22/952548) is retained here. Here the Hautawa Shellbed and Upokonui Sandstone crop out at the base of the abandoned Parikino floodplain. The formation can be easily traced across the Parikino / Parihauhau interfluve, with the loose, unvegetated Upokonui Sandstone highly visible in the landscape. The easternmost occurrence of the Whariki Formation is in the Pohangina valley at Komako, where it crops out on the banks of the Te Ekaou Stream between site 72 at T23/577174 (where it is in contact with Mesozoic greywacke) and T23/570179. In the Rangitikei River section, the formation crops out intermittently in riverbanks between T22/436457 and the base of the Tuha Shellbed at T22/433446. Between the Watershed Road and Parihauhau valley sections, the top of the formation is not well exposed. In the Watershed and West Road sections, the formation crops out in steep, clean bluffs stratigraphically above and to the south of the Hautawa Shellbed, which is exposed at sites 71 and 70 in each of these sections, respectively. The top of the formation was not located in either of these sections during fieldwork for this study. In Turakina valley, the formation is exposed in the southern banks of the gorge at Otari, with the distinctive Hautawa Shellbed marking the base of the formation at S22/232498, and the top of the Upokonui Sandstone marking the top of the formation (Naish *et al.*, 2001). In the Whangaehu valley, the lower parts of the Whariki Formation are well exposed on the roadside just north of Mangamahu settlement, with the lower part occurring at site 65 (S22/121524). The upper parts not well exposed, but probably crop out in the Whangaehu River banks in the vicinity of Mangamahu itself. The Whariki Formation also crops out in the Mangawhero River valley, in a large bluff above State Highway 4 roadside at site 54 (S22/062537), but the upper part is inaccessible. In the Parihauhau Road section, the formation crops out continuously in a bluff on the right bank of the Upokongaro stream at site 51 (S22/972554), with all of the formation easily accessible. The formation maintains a similar character across into the Wanganui and Kauarapaoa valleys, where in the latter it is best exposed above the Kauarapaoa Stream at R22/900554. There it is continuously exposed downstream for several hundred metres on the left bank of the stream. At Wairangi, the Whariki Formation caps both Ruawahia and Kaihokahoka Peaks R21/836611), where the Hautawa Shellbed grades into Kuranui Limestone. The formation crops out in a quarry near Rangitatau East Road at site 19 (R21/763628), and caps most of the hills and ridges between this section and the Rangitatau West Road section, where it is well exposed near the top of Okiwa Trig, and also in the southern face of Windy Point quarry near Kuranui Trig at site 12 (R22/687569).

THICKNESS: 61 m (Pohangina), 77.5 m (Rangitikei), > 43 m (Whangaehu), > 43 m (Mangawhero), 52.5 m (Parihauhau), 28 m (Wanganui), 46.5 m (Kauarapaoa), > 7.5 m (Wairangi), > 12 m (Kai-Iwi), > 10 m (Paparangi), 32 m (Okiwa).

(Wkcml) Hautawa Shellbed / Kuranui Limestone: 3 m (Pohangina), 0.5 m (Rangitikei), 2 m (Watershed Road), 2 m (West Road), 3 m (Whangaehu), 3 m (Mangawhero), 3.5 m (Parihauhau), 3 m (Wanganui), 4 m (Kauarapaoa), 7.5 m (Wairangi), 12 m (Kai-Iwi), ~ 10 m (Paparangi), 17 m (Okiwa).
(Wkzml) "Tuha Siltstone": 58 m (Pohangina), 45 m (Rangitikei), 70 m (Watershed Road), 70 m (West Road), > 40 m (Whangaehu), 1 m (Mangawhero), 2 m (Parihauhau).
(Wksml) Upokonui Sandstone: 32 m (Rangitikei), 18 m (Watershed Road), > 40 m (Mangawhero), 47 m (Parihauhau), 25 m (Wanganui), 42.5 m (Kauarapaoa), 15 m (Okiwa).

AGE: early-Nukumaruan.

LITHOLOGY: The Whariki Formation displays considerable lateral variation in lithology, geometry and thickness across the 103 km of its exposure. In the eastern sections (Te Ekaou, Rangitikei, Watershed Road, West Road, Turakina, Whangaehu), it is thickest, and is comprised of the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone, in ascending stratigraphic order. In the central parts of the basin (Mangawhero, Parihauhau, Wanganui, Kauarapaoa), it is represented by the Hautawa Shellbed and the Upokonui Sandstone. West of Kauarapaoa valley, in the Wairangi, Paparangi and Okiwa sections, the Kuranui Limestone and Upokonui Sandstone comprise the formation.

Hautawa Shellbed /Kuranui Limestone Member.

NAME: The name "Hautawa Shellbed" was proposed by Fleming (1953) as a formalisation of the name "Hautawa Shell Reef" of Feldmeyer *et al.* (1943), after its exposure on the now abandoned Old Hautawa Road on the Rangitikei-Turakina watershed at T22/326484. Fleming (1953) gave the Hautawa Shellbed formation status. Naish & Kamp (1995) made the Hautawa Shellbed a member of their Tikapu Formation following work in Rangitikei River valley, but the unsuitability of this formation for strata west of the Rangitikei section led to the creation of the Whariki Formation by McIntyre & Kamp (1998). The Hautawa Shellbed is a member of the Whariki Formation. This practice is continued here. Naish *et al.* (2001) have reverted to the original formation status of Fleming (1953) for the Hautawa

Shellbed. Prior to this study, the Kuranui Limestone, which was identified and named by Fleming (1953) and occurs only west of Kauarapaoa valley, was considered to be probably unrelated to the Hautawa Shellbed (Fleming, 1953, p. 130). However, this study has demonstrated that the Kuranui Limestone and the Hautawa Shellbed occur at the same stratigraphic horizon and are correlatives. The separate names are retained in recognition of the two major facies groups common to this unit. (Maori: Hau = wind; tawa = native New Zealand tree *Beilschmiedia tawa.* Kura = red, nui = big; probably a reference to the now extinct New Zealand Moa, a large flightless bird of which there were many species, some up to 2 m in height. The largest, *Dinornis giganteus,* is possibly the subject of the name Kuranui).

TYPE LOCALITY AND DISTRIBUTION: The type locality of Fleming (1953) at T22/ 325484 (GS 3096 of Fleming) is retained, on the now abandoned "Old Hautawa Road", near the end of West Road in the Porewa valley near Ohangaiti. The Hautawa Shellbed has been identified onlapping Mesozoic greywacke in the Pohangina valley at Komako, where it crops out in the Te Ekaou Stream at site 72 (T23/577174). In the Rangitikei River valley, the shellbed crops out in the low riverside terrace at T22/436457, and can be traced sporadically across the valley to Watershed Road, where it crops out on the roadside at site 71 (T22/371472). In the Turakina valley, the Hautawa Shellbed crops out in the gorge at Otairi, where it forms a continuous protruding, undercut ledge on both sides of the sides of the gorge (S22/232498). The best access to the shellbed is beneath a bridge on a farm track at S22/235488. The shellbed is well exposed within the Whangaehu River valley near Mangamahu, where it crops out on Creek Road at site S22/145521 (GS 4369 of Fleming, 1953), on the abandoned "Ridge Road" at site 64 (S22/143534) (GS 4355 of Fleming, 1953), and on the Whangaehu valley roadside at site 65 (S22/120524). In the Mangawhero valley, the Hautawa Shellbed occurs in a prominent bluff about 30 m above State Highway 4 at site 54 (S22/062537) (GS 4357 of Fleming, 1953). Between the Mangawhero and Parihauhau sections, Fleming (1953) reported several localities in which the Hautawa Shellbed crops out, namely GS collections 4204 (S22/027568), 4225 (S22/015569), 4206 (S22/994561) and 4201 (S22/981546); none of these localities were visited or located during fieldwork for this study. However, it is well exposed beside a farm track at the base of a bluff above the Upokongaro Stream at site 51 (S22/982555) about 1 km downstream from the confluence of the Upokonui and Kahakaha Streams. In the Wanganui River valley, the shellbed is well exposed in the vicinity of Parikino settlement, where it crops out beside the road at S22/941545 near a woolshed across the road from Parikino School, and can be traced intermittently across the base of the southern valley wall to site 46 (S22/952548). The shellbed also occurs at the top of a hill near Te Rimu at S22/963570. In the Kauarapaoa River valley, the Hautawa Shellbed crops out and caps a plateau above the Kauarapaoa Stream at S22/909565, and also occurs intermittently above the School Shellbed beside the stream between R22/900554 and roadside at site 32 at R22/898548 (GS 4198 of Fleming, 1953). The Hautawa Shellbed was not observed due to poor access and exposure between the Kauarapaoa and Wairangi sections, where in the latter, the facies has changed. There, the shellbed is represented by the Kuranui Limestone, which crops out near the top of Ruawahia and Kaihokahoka Peaks. From this locality, the limestone can be observed cropping out near-continuously on the western face of the Kai-Iwi valley walls, dipping gently to the south to the confluence of the Kai-Iwi and Tatarongo Streams, and is well exposed beside the Kai-Iwi stream at R22/825568. The Kuranui Limestone caps Rangitatau Peak (558 m) near Paparangi, where it crops out poorly on the roadside at R22/770630, but is best exposed in two abandoned quarries, at site 19 (R21/763628) and R21/763621, approximately 1 km south of site 19. The limestone appears to cap most of the hills between Rangitatau and Okiwa, where at the latter it crops out continuously beside Rangitatau West Road for several kilometres between Okiwa, Te Rama and Kuranui Peaks. The best exposure in this section is in the quarry at Windy Point (Site 12, R22/687569). It was not observed west of this locality. However, Fleming (1953) reported and mapped Kuranui Limestone near the coast within the Nukumaru Dune Complex, a locality not investigated during this study.

THICKNESS: 3 m (Pohangina), 0.2 m (Rangitikei), 2 m (Watershed Road), 2 m (West Road), 3 m (Whangaehu), 3 m (Mangawhero), 3.5 m (Parihauhau), 3 m (Wanganui), 4 m (Kauarapaoa), 7.5 m (Wairangi), 12 m (Kai-Iwi), ~ 10 m (Paparangi), 17 m (Okiwa).

AGE: early-Nukumaruan. First occurrences of *Zygochlamys delicatula, Mesopeplum convexum, Phialopecten triphooki* and the planktic foraminifer *Globorotalia crassula.* Last occurrences of *Crassostrea ingens* and *Phialopecten thomsoni.*

LITHOLOGY: The Hautawa Shellbed is probably the most laterally extensive of the Late Pliocene and Pleistocene Wanganui Basin shellbeds, and thus contains a significant variety of lithologies and fossils. Typically the Hautawa Shellbed is at least 2 m thick, and is richly fossiliferous with a diverse assemblage of skeletal carbonate material. Preservation is best in the central parts of the basin, where the unit is a moderately cemented shellbed. There fauna becomes more abraded, poorly preserved and weathered in the Kuranui Limestone in the west and where the shellbed is in contact with Mesozoic basement greywacke on the eastern flank of the Ruahine Range. At the latter site (72), the shellbed takes the form of a fossiliferous conglomerate, which occurs as lenses within the relief on the greywacke paleotopography, and has two distinct parts. The lower part is mainly comprised of well-rounded greywacke pebbles and cobbles up to 50 cm in length unconformably overlying indurated greywacke, with common disarticulated, unoriented, poorly preserved and abraded fossils, including *Cellana, Crassostrea, Ostrea, Phialopecten thomsoni, Tawera subsulcata, Zethalia coronata* and *Tegulorynchia.* The upper part of the conglomerate is marked by an abrupt decrease in clast size, with well-rounded greywacke pebbles (5-6 mm) comprising a clast-supported matrix in which rare, poorly preserved, unoriented, disarticulated, thick-shelled bivalves and scallops (*Tucetona, Purpurocardia* and *Phialopecten*) are common. The lack of thin-shelled bioclasts and the iron oxide coating of pebbles indicate a high level of meteoric dissolution of carbonate. In the Rangitikei River section, the shellbed is the least fossiliferous and thinnest (0.2 m) compared with all other exposures in the basin; here it forms a loosely packed, matrix-dominated shellbed conformably overlying Mangapanian siltstone. Common, poorly preserved, near-*situ Atrina Ostrea, Pratulum, Caryocorbula, Calliostoma, Penion, Amalda* and *Antalis* occur within a siltstone matrix, with no discernible internal microstratigraphic bedding or patterns in faunal occurrence. In the Watershed and West Road sections, the Hautawa Shellbed is significantly thicker and more fossiliferous than in the Rangitikei, and has a similar appearance and lithology in the two sections. Here, 2 m of closely packed fossil molluscs in a generally well-preserved state conformably overlie siltstone, with common, near-*situ Aulacomya, Perna, Anomia, Patro, Crassostrea, Ostrea, Chlamys, Zygochlamys* and *Purpurocardia* within the sandstone matrix. The upper parts of the shellbed are less fossiliferous, with loosely packed, *in situ* brachiopods (*Tegulorynchia, Neothyris*), molluscs (*Bathytoma, Amalda, Antalis*) and bryozoans occurring in roughly equal quantities within a siltstone matrix. In the Whangaehu valley, the moderately well cemented nature of the shellbed causes it to form a prominent horizon, 3 m thick, which is well exposed in the landscape. There, the base of the shellbed is erosionally unconformable, with up to 0.2 m of local relief on the contact, and *Ophiomorpha* trace fossil borrows infilled with a sandy shell hash extending 25 cm into the underlying siltstone. At its exposure on Ridge Road, the shellbed itself is comprised of three main parts, which intergrade. The lowermost 0.5 – 1 m part of the shellbed contains a diverse assemblage of fossils, with well-preserved, reworked, common *Zygochlamys delicatula, Pleuromeris, Purpurocardia, Talabrica, Crepidula* and

Amalda. The middle and upper parts of the shellbed are less fossiliferous and less diverse, with *Sigapatella* and *Crepidula* comprising the middle 0.8 m-thick part of the shellbed, and the upper 1.2 m contains almost exclusively *Ostrea* and *Magasella*. The Hautawa Shellbed maintains a similar appearance into the Mangawhero River valley, where it is 3 m thick, and contains *Ostrea chilensis, Chlamys gemmulata* and *Purpurocardia purpurata* in abundance throughout the unit. A few disarticulated valves of *Zygochlamys delicatula* occur in the lower part of the shellbed, with *Aeneator, Pratulum* and *Taniella* common in the upper parts. Preservation of fossils is generally good, with most bioclasts occurring as loosely packed and disoriented within the fine sandstone matrix. The base of the shellbed is erosionally unconformable on underlying Parikino Formation siltstone. In the Parihauhau section, the Hautawa Shellbed is well exposed, with the unconformable base forming a slight undercut ledge. However, the poorly preserved nature of the remnant fossils, and the occurrence of only calcitic skeletal material (*Notosaria* and *Neothyris*) indicates significant post-depositional meteoric carbonate dissolution, which has probably dissolved most of the fossil material originally comprising the shellbed. In the Wanganui River valley at Parikino, the Hautawa Shellbed unconformably overlies Mangapanian Parikino Formation siltstone with 0.3 m of relief on the contact at most sites, but it appears to have a conformable base at Te Rimu (S22/963570). Typically, the lower 0.5 m of the shellbed consists of a reworked, densely packed shell coquina, with common disarticulated and reworked fossils (*Pleuromeris, Purpurocardia, Ostrea, Mesopeplum, Chlamys* and *Crepidula*) within a sandstone matrix. This passes upwards into a less fossiliferous siltstone (1.5 m thick), which is in turn overlain by an upper shellbed about 1 m thick, in which *Ostrea, Maoricolpus, Atrina, Sigapatella* and brachiopods (*Neothyris, Waltonia, Notosaria*) are common. In the Kauarapaoa valley, the Hautawa Shellbed crops out only a few metres above the School Shellbed, but they can be easily differentiated by the few metres of siltstone separating them, by the unconformity at the base of the Hautawa Shellbed, and by the distinctive Upokonui Sandstone resting directly on top of the Hautawa Shellbed. Here, the shellbed is very similar to its equivalent in the Wanganui River section, with well-preserved, diverse fossils randomly oriented within a sandy matrix including common *Anomia, Patro, Chlamys, Ostrea, Divaricella, Eumarcia, Crepidula* and *Fellaster*. The lower part of the shellbed is up to 2 m thick. This lower part is conformably overlain by a metre of weakly bedded siltstone, above which is the upper part of the shellbed, 1 m thick, less fossiliferous and diverse than the lower shellbed, and containing common *Chlamys, Ostrea, Sigapatella, Xymene, Almada* and the brachiopod *Neothyris*. To the west of Kauarapaoa valley, the Hautawa Shellbed grades laterally into the Kuranui Limestone, which occurs in the Wairangi and Paparangi sections as a moderately cemented, cross-bedded, flaggy, sandy shell–hash (calcirudite) limestone scoured into Okiwa Subgroup siltstone. Preservation of fossils is poor, the weathered limestone being comprised of disarticulated, fragmented and abraded mollusc, bryozoan and barnacle bioclasts. However, rare *Phialopecten* and *Fellaster* occur near the base, and *Ostrea, Crassostrea* and casts of *Crepidula* are common in the central and upper parts. At Okiwa, the limestone reaches its greatest thickness (17 m) and is composed of mainly highly abraded shell fragments and sandstone, with occasional near-complete fossil molluscs. There, the limestone is flaggy and cross-bedded, with thin loose sandstone and shell gravel lenses infilling the intervals between flags. The lowermost 0.4 m is very fossiliferous, with common *Phialopecten triphooki, Patro* and leached casts of indeterminate bivalves. *Crassostrea* is common at the top of this lower part. The main part of the limestone becomes progressively sandier upwards, gradationally passing into fine–medium sandstone with blocky concretionary flags 3 – 5 cm thick separating sandstone foresets of similar thickness. Cross-bedding is most noticeable in the lower 3 – 4 m of the limestone, having lesser dip angles in the upper parts. Above the lower 0.4 m, fossils become less well-preserved and diverse, with mainly calcitic taxa such as *Mesopeplum convexum, Chlamys gemmulata, Phialopecten triphooki, Ostrea, Patro* and *Neothyris*. Internal casts of *Perna* and *Crepidula* are also found, with the latter abundant in the central parts of the limestone.

DEPOSITIONAL ENVIRONMENT: The Hautawa Shellbed is one of very few shellbeds in the Wanganui Basin to display a wide range of facies and faunas across the width of the basin, allowing a relatively precise reconstruction of the depositional environment. As with most shellbeds in the basin, the gradation from shallow-water fossils near the base of the unit (e.g. *Eumarcia, Fellaster, Divaricella, Myadora*) is associated with an unconformable base to the shellbed, which accumulated in a nearshore, high to moderate-energy erosive environment. An increase in water depth during accumulation of the shellbed is indicated by the increase in the concentration of deeper-water fossil species (e.g. *Pratulum, Antalis, Pelicaria*), improving biostratonomic preservation and the progressive rarity of shallower water molluscs. The lack of shallow water taxa in the Rangitikei River section suggests that this locality was close to the greatest depth of deposition for the unit. The Kuranui Limestone is considered to be the shallow-water expression of the Hautawa Shellbed, with a sustained high-energy environment indicated by the high level of mechanical abrasion of its constituent bioclasts, and by the large scale (sandwave) cross-bedding that occurs throughout the unit. Thus the Kuranui Limestone represents nearest preserved approach to the western basin margin during the earliest Nukumaruan. The conglomerate in the Pohangina valley is considered to represent the southeastern margin of the basin, as it onlaps basement, and contains numerous extremely shallow-water, rocky shoreface fossils (*Zethalia coronata, Haliotis, Cellana, Dosinia subrosea* and *Divaricella huttoniana*). The first occurrence of the subantarctic scallop *Zygochlamys delicatula* within the Hautawa Shellbed and the extinction of *Maoricardium, Crassostrea ingens* and *Phialopecten thomsoni* just before its deposition has traditionally been taken as evidence for climatic deterioration during deposition of the shellbed; this is discussed further in Chapter 7.

Upokonui Sandstone Member.

NAME: The Upokonui Sandstone is named after Upokonui Stream (a tributary of the Upokongaro Stream) and was first described by Fleming (1953) for the distinctive loose sandstone cropping out immediately above the Hautawa Shellbed in the western parts of Wanganui Basin. The name is retained here, but as a member of the Whariki Formation, rather than a discrete formation as originally proposed by Fleming (1953). This study has revealed that the Upokonui Sandstone is in fact the "Tuha Sand" of Feldmeyer *et al.* (1943), and "Tuha Sandstone" of Naish & Kamp (1995), but the name "Upokonui" is used to avoid confusion with the "Tuha Shellbed", an informal name for the shellbed succeeding the Hautawa Shellbed (Naish *et al.* 1996, 1997, 2001; Orpin *et al.* 1998). Thus, in this study, the name "Upokonui Sandstone" also includes the "Tuha Sandstone" of previous workers. (Maori: Upoko = head, nui = big).

TYPE LOCALITY AND DISTRIBUTION: No formal type locality was chosen by Fleming (1953) for the Upokonui Sandstone, other than "It is typically developed in cuttings on Parihauhau Road, in the valley of Upokonui Stream". However, no such roadside exposures were found during fieldwork for this study, the only exposures of the Upokonui Sandstone on the Parihauhau Road roadside being above the Upokongaro Stream at S22/986558 and S22/983546. Neither of these is suitable for a type locality, due to incomplete exposure of the unit at each site. The Upokonui Sandstone is well exposed on the western bank of the Upokongaro Stream at site 52 (S22/981555). However, the type locality designated here is in the Wanganui River valley near Parikino, where it was described by McIntyre & Kamp (1998) above the Hautawa Shellbed between sites 46 and 47 (S22/952548). The entire unit is well exposed there, and crops out variably along the base of the hills south of Parikino settlement, with glimpses of the unit exposed in roadside cuttings above the Hautawa Shellbed in road cuttings immediately south of Parikino School, before dipping beneath the Wanganui River at S22/537936. In the eastern part of Wanganui Basin, the Upokonui Sandstone is less distinctive. It is not present in the Pohangina valley, but crops out beneath the Tuha Shellbed in the banks of the Rangitikei River in the vicinity of the Otara Road Bridge at T22/434450. In Turakina valley, the Upokonui Sandstone crops out south of Otari (Naish *et al.* 2001). It is poorly exposed in the Whangaehu River valley, where it was not observed. However, it is predicted to crop out in the inaccessible, vertical river banks near Mangamahu settlement. The unit is well exposed above the Hautawa Shellbed in the Mangawhero valley at site 54 (S22/062537), and can be traced intermittently across the Mangawhero / Upokonui watershed to the Parihauhau and Wanganui River sections, as described above. In the Kauarapaoa valley, the Upokonui Sandstone crops out typically near Raorika, above the Hautawa Shellbed at R22/900554, and on the east bank of the Kauarapaoa Stream at R22/897548, about 0.1 km north of a footbridge. The unit is not well exposed in the Wairangi, Paparangi or Okiwa sections, but crops out in Windy Point Quarry at Kuranui (site 12, R22/687569).

THICKNESS: 0 m (Pohangina), 32 m (Rangitikei), 18 m (Watershed Road), ~ 40 m (Mangawhero), 47 m (Parihauhau), 25 m (Wanganui), 42.5 m (Kauarapaoa), 15 m (Okiwa).

AGE: early-Nukumaruan.

LITHOLOGY: The Upokonui Sandstone is one of the most distinctive units within the Wanganui Basin Pliocene succession, cropping out in the western parts of the basin as a loose, unvegetated, well-sorted, low-angle cross-bedded, fine yellow-brown micaceous quartz sandstone. Unlike the underlying Mangapanian sandstone beds, the Upokonui Sandstone has abundant tractional sedimentary structures, with low-angle tabular and trough cross bedding becoming more developed to the west. In all exposures, the lower contact of the sandstone is conformable with the underlying siltstone (to the east of Mangawhero valley), and it is conformable with the Hautawa Shellbed / Kuranui Limestone at and to the west of Mangawhero valley. The upper contact is unconformable with minor local relief (up to 0.5 m) beneath the succeeding shellbed. In the vicinity of Rangitikei River, the Upokonui Sandstone is a pale grey-brown, sparsely fossiliferous, bioturbated fine sandstone, which coarsens upwards from massive, silty fine sandstone in the lower parts, to a trough cross-stratified, fine to medium sandstone, and then to low-angle, planar cross beds in the upper parts. In the Mangawhero valley, the unit is horizontally bedded, with 0.2 m thick alternating beds of sandy siltstone and silty sandstone throughout. West of this locality, the Upokonui Sandstone does not change character significantly between the Parihauhau, Wanganui and Kauarapaoa sections, being a loose, unconsolidated, yellow brown micaceous sandstone, with abundant tabular concretionary horizons, low-angle cross-bedding and intense bioturbation. In the Parihauhau Road section the sandstone is fossiliferous in the uppermost 5 m, with the urchin *Fellaster zelandiae* common. Extensive *Ophiomorpha* burrows infilled with broken shell fragments extend downwards for 1 m into the sandstone from the unconformity at the base of the overlying shellbed. In Wanganui valley, the Upokonui Sandstone is relatively thin, and contains a total of 21 tabular calcite concretions about 0.1 m thick, separated by about 1 m of fine sandstone. The urchin *Fellaster zelandiae* is commonly found in clusters cemented into the upper surface of the concretionary horizons. The top of the sandstone is marked by 1 m of spectacularly dense *Ophiomorpha* burrows, similar to those in the Parihauhau Road section. In Kauarapaoa valley, the sandstone has three distinct parts. The lowermost part (22 m thick) is a massive, featureless, well-sorted fine sandstone. The central part (12 m thick) is comprised of a low–angle tabular cross–bedded fine sandstone separating thin horizontal concretionary horizons less than 0.1 m thick every 2 m or so. Abundant *Fellaster* within a concretionary horizon marks the boundary between the middle and upper parts of the sandstone. The uppermost 8.5 m-thick part of the unit being an extensively bioturbated medium sandstone containing the micromollusc *Myllitella*, with no apparent bedding structures between 0.2 m-thick concretionary flags, each of which is separated by ~ 1 m of loose sandstone. At Kuranui, the Upokonui Sandstone is 15 m thick, and is made up of three parts: The lower 2.5 m is a low-angle cross-bedded, well-sorted, fine brown sandstone, which is overlain by a 5.5 m-thick flaggy sandstone with 3–5 cm thick flags separating high angle (>20°) foresets of similar thickness. The upper 7 m consists of trough–bedded sandstone, which becomes more massive in the upper 3 metres. Fossils in this upper part of the sandstone include *Ostrea, Phialopecten, Mesopeplum, Fellaster* and barnacles (*Balanus*).

DEPOSITIONAL ENVIRONMENT: The increase in tractional sedimentary structures, and the dominance of shoreface fossils in the middle and upper parts of the unit (*Fellaster, Mylitella*) indicate a shallowing from the (probably) slightly deeper, massive sandstone in the lower parts, where an inner-shelf to nearshore depositional environment is inferred from the occurrence of the benthic foraminifera *Cibicides* aff. *notocenicus, Quinqueloculina, Elphidium charlottensis* and rare *Ammonia beccarii*. Furthermore, the increase in the occurrence of cross-bedding within the sandstone in the western part of its exposure indicates a closer proximity to a paleoshoreline compared with the eastern parts of the basin, where the sandstone shows less evidence of wave-action during accumulation.

Figure 3.2: Mangapani Shell Conglomerate beside Waitotara valley Road. Note bedded siltstone / sandstone separating the upper and lower carbonate rich parts.

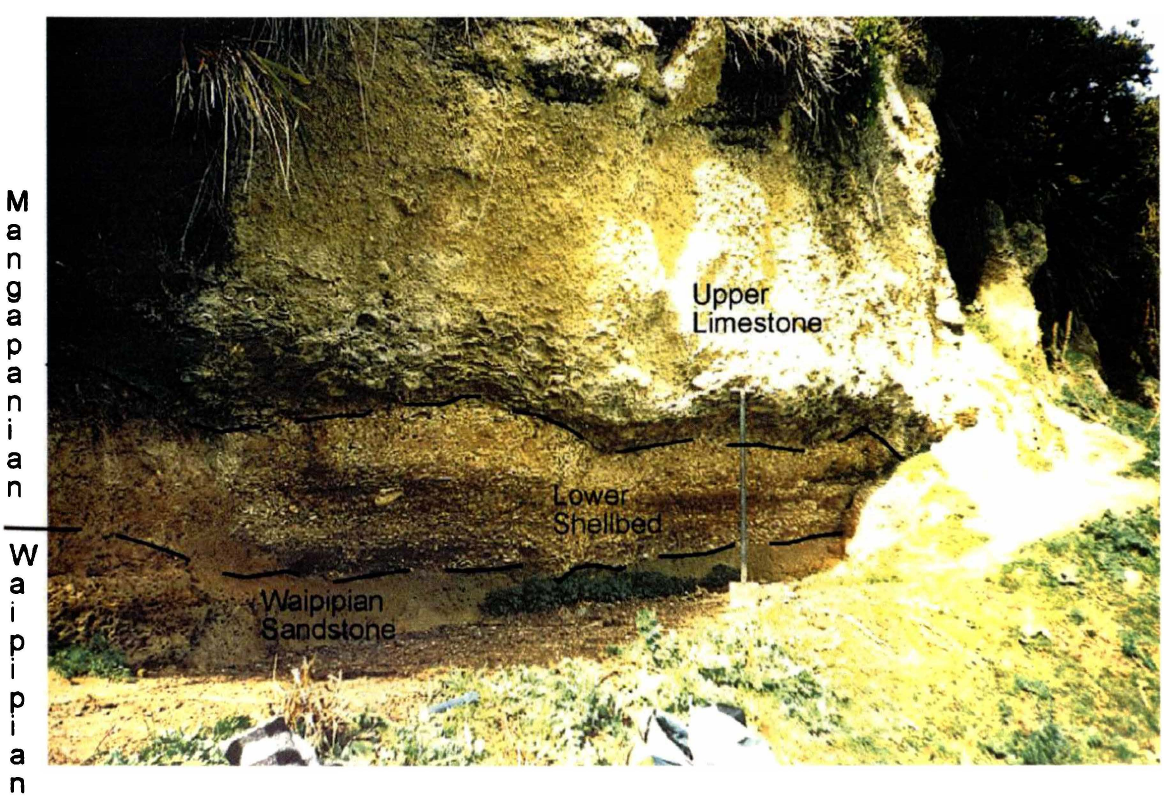

Figure 3.3: Mangapani Shell Conglomerate, at its type locality in Mangapunipuni valley. Note direct contact between upper and lower parts of the unit. Spade is 1.1 m in length.

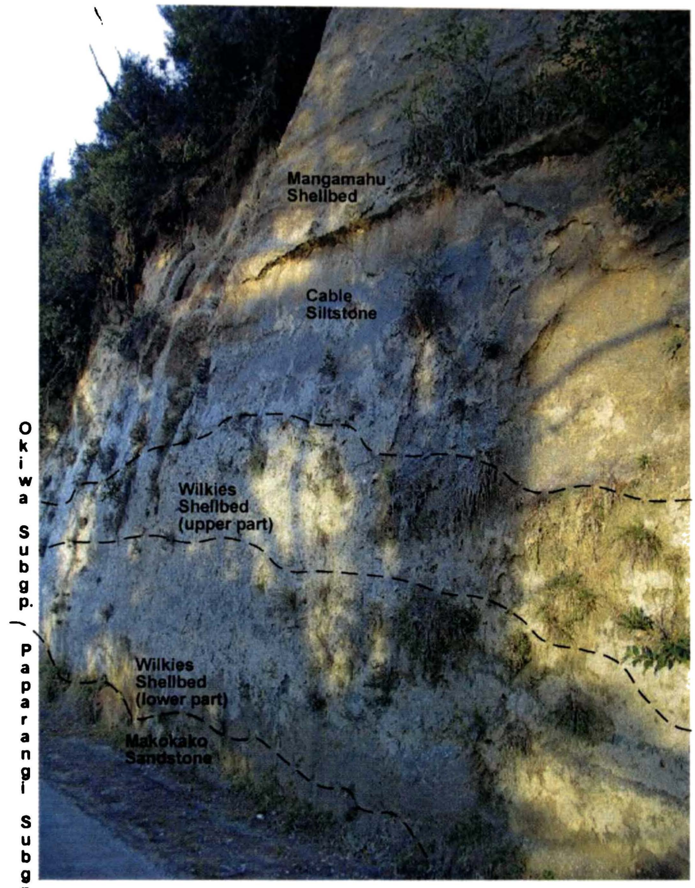

Figure 3.4: Wilkies Shellbed at Paparangi, Rangitatau East Road. Here, the Wilkies Shellbed unconformably overlies the Makokako Sandstone, and the Mangamahu Shellbed unconformably overlies the Cable Siltstone. (GS 4209; Fleming, 1953).

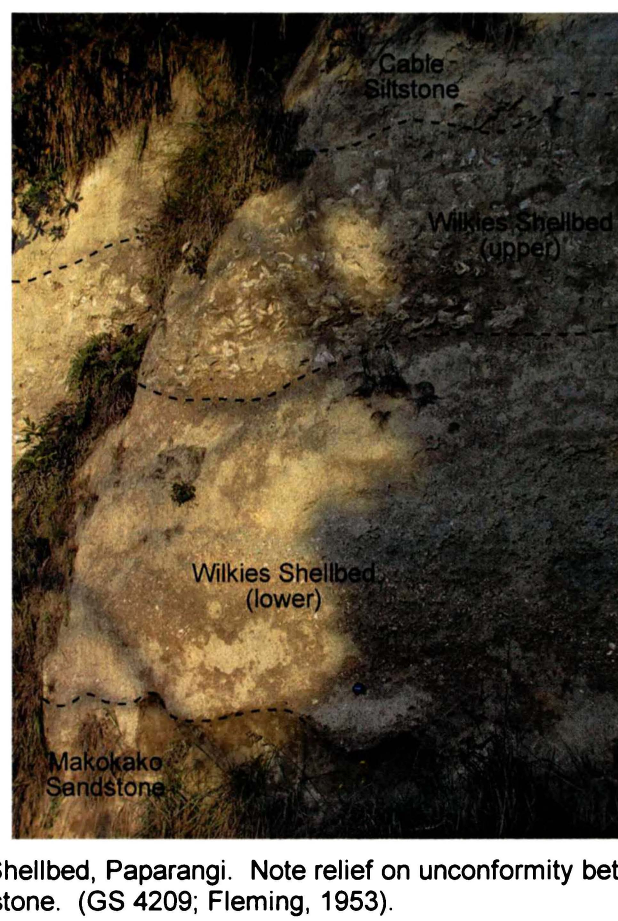

Figure 3.5: Wilkies Shellbed, Paparangi. Note relief on unconformity between Wilkies Shellbed and Makokako Sandstone. (GS 4209; Fleming, 1953).

Figure 3.6: Otere Tephra, Kauarapaoa valley. Otere Shellbed concealed by talus in lower part of photo. Knife is approx. 15 cm in length. (Site 22)

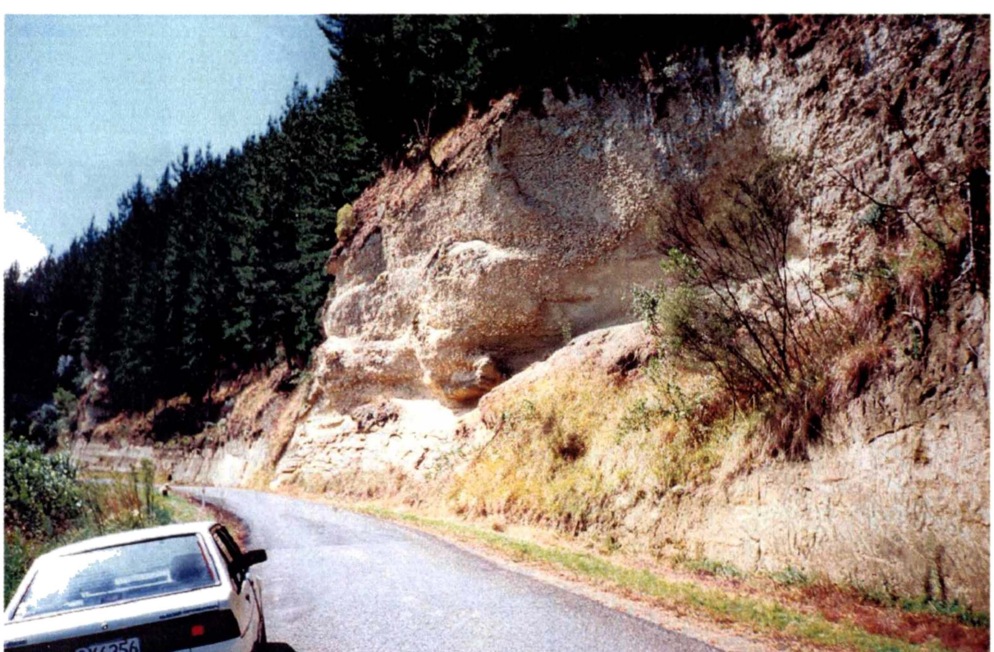

Figure 3.7: Wilkies Shellbed, Wanganui River Road. Here, the Wilkies Shellbed conformably overlies Makokako Sandstone, and is up to 15 m thick. Note horizons of *Crassostrea* extending into sandstone lens within shellbed.

Figure 3.8: Close-up of Wilkies Shellbed, Wanganui River Road. Most *Crassostrea* are in situ, closely packed, and articulated.

Figure 3.9: Near base of Mangarere Sandstone, West Road, Porewa valley. Note channel-like bedding structures within sandstone. Base of sandstone not exposed here.

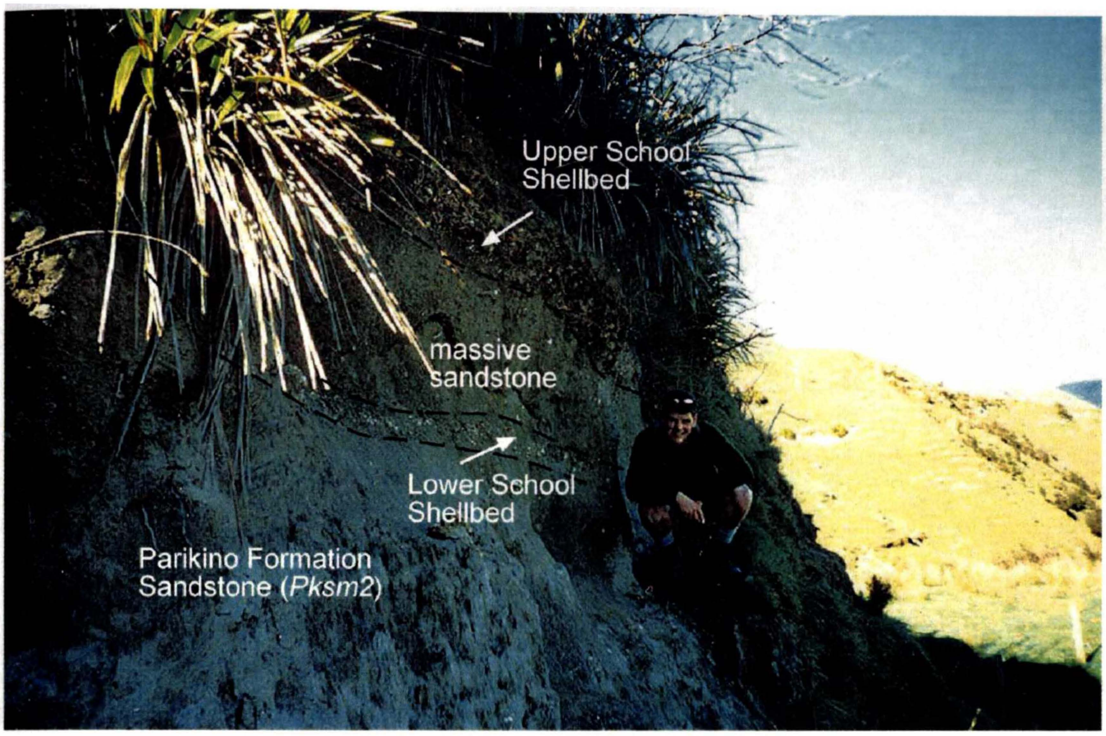

Figure 3.10: School Shellbed, Kauarapaoa valley. Here, a massive, fossiliferous sandstone separates the lower, aragonitic bivalve dominated part of the shellbed from the upper, oyster-rich part.

Figure 3.11: Base Of Mangapani Shell Conglomerate, Waitotara valley roadside. Here, the base of the shellbed unconformably overlies Waipipian sandstone, and contains abundant *Eumarcia* and greywacke pebbles.

Figure 3.12: Base of Hautawa Shellbed, at site 46 near Parikino, Wanganui River valley. Base of shellbed is unconformably cut into Mangapanian Parikino Formation siltstone.

Figure 3.13: Hautawa Shellbed, at site 64, Ridge Road, Mangamahu, Whangaehu River valley. Base of shellbed unconformably overlies Mangapanian Parikino Formation siltstone.

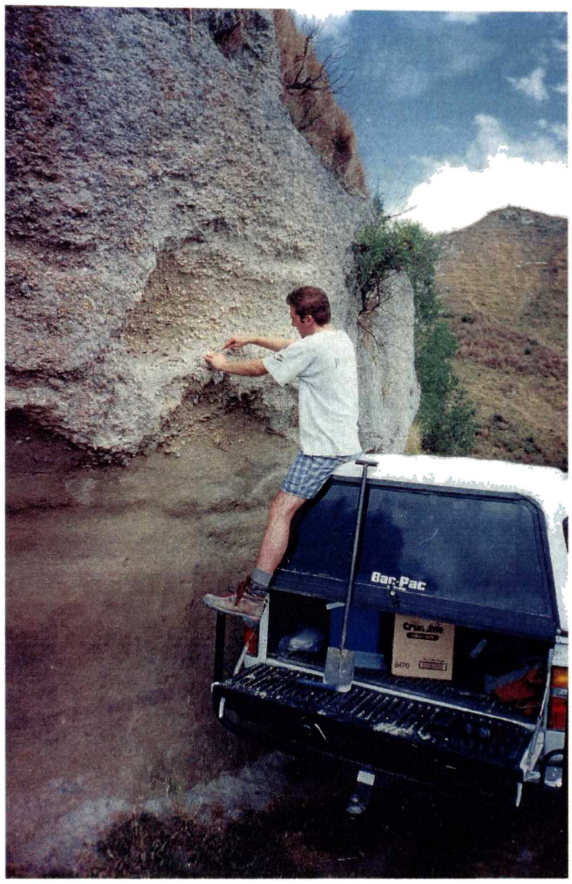

Figure 3.14: Base of Hautawa Shellbed, at same locality as above (Site 64). The scallop *Zygochlamys delicatula* is abundant in the lower part of the shellbed at this locality.

Figure 3.15: Kuranui Limestone, Windy Point Quarry, Rangitatau West Road near Okiwa Trig. Here, it is 17 m thick, and note large tabular and herringbone cross-beds throughout unit. (Site 12).

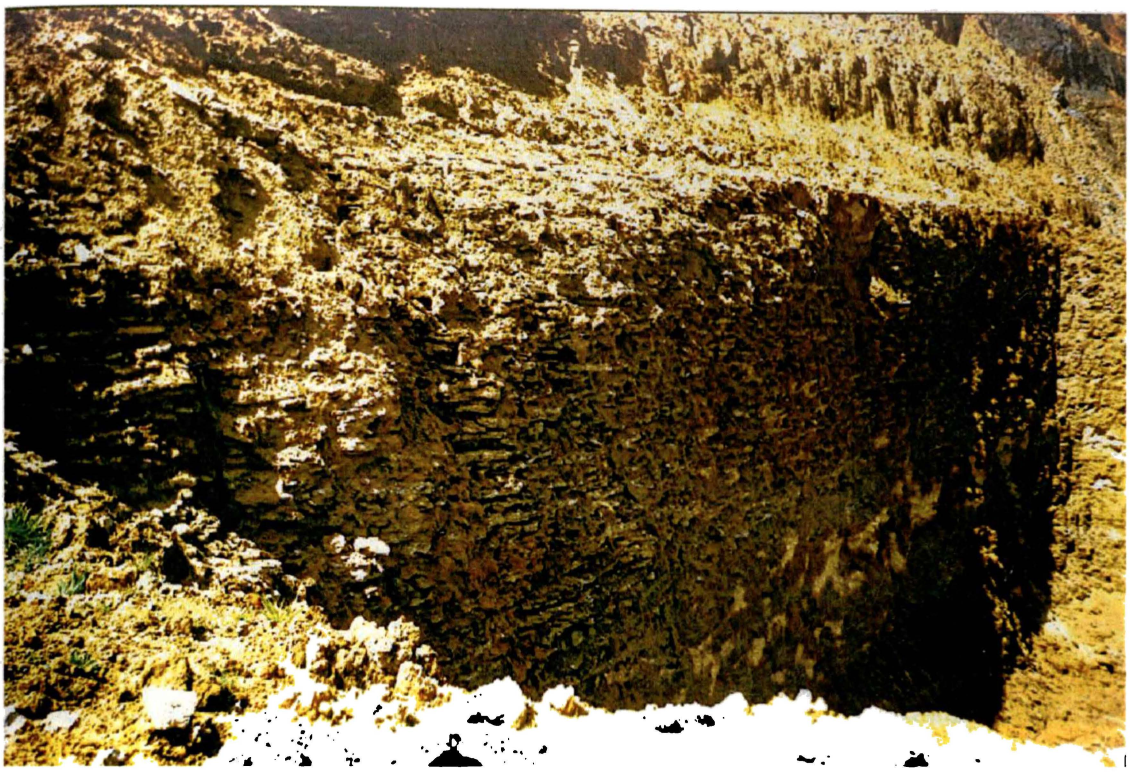

Figure 3.16: Top of Kuranui Limestone, site 12, 200 m north of previous photo. Here, decimetre scale tabular blocky concretions are interbedded with loose sandstone lenses of similar thickness. The Upokonui Sandstone / Kuranui Limestone contact occurs at the benched surface near top of photo. Height of face is about 10 m.

Figure 3.17: Upokonui Sandstone at site 46, near Parikino, Wanganui River valley. The central parts of the sandstone here are composed of ~ 1m of sandstone interbedded with ~ 0.1 m tablular concretionary horizons. The loose sandstone is intensely bioturbated.

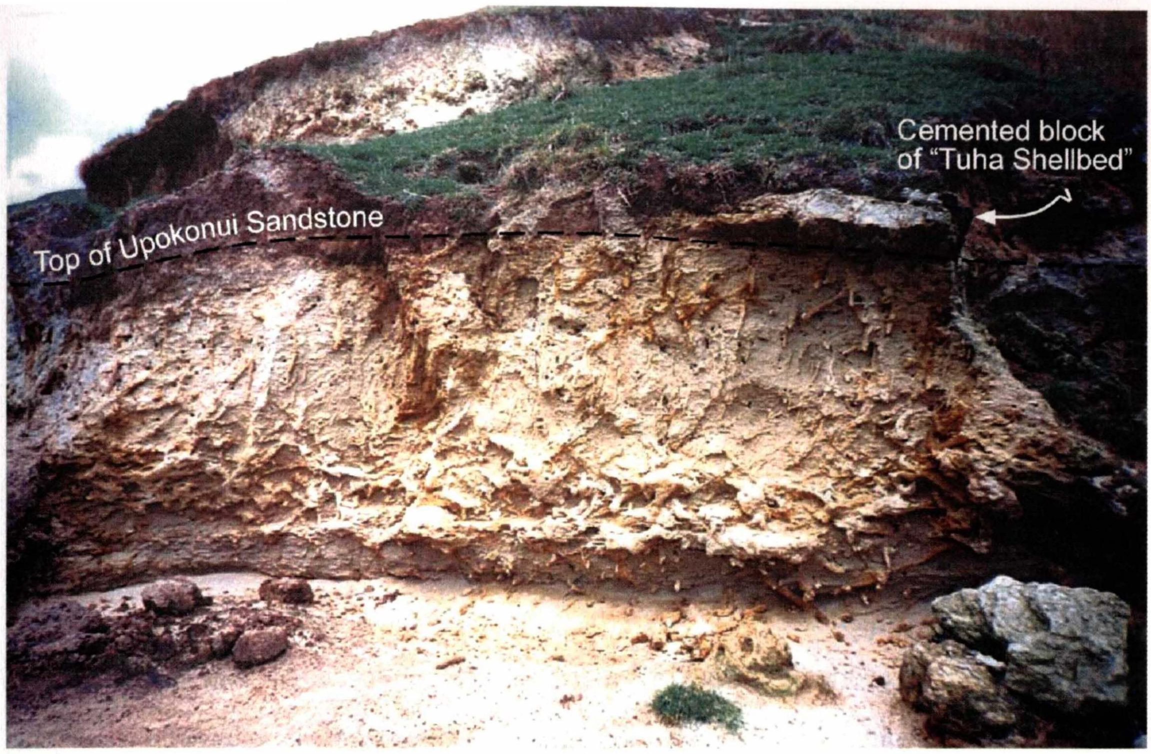

Figure 3.18: Top of Upokonui Sandstone at site 46 (above). Partially cemented *Ophiomorpha* burrows extend ~ 1 m into the sandstone from the base of the overlying shellbed.

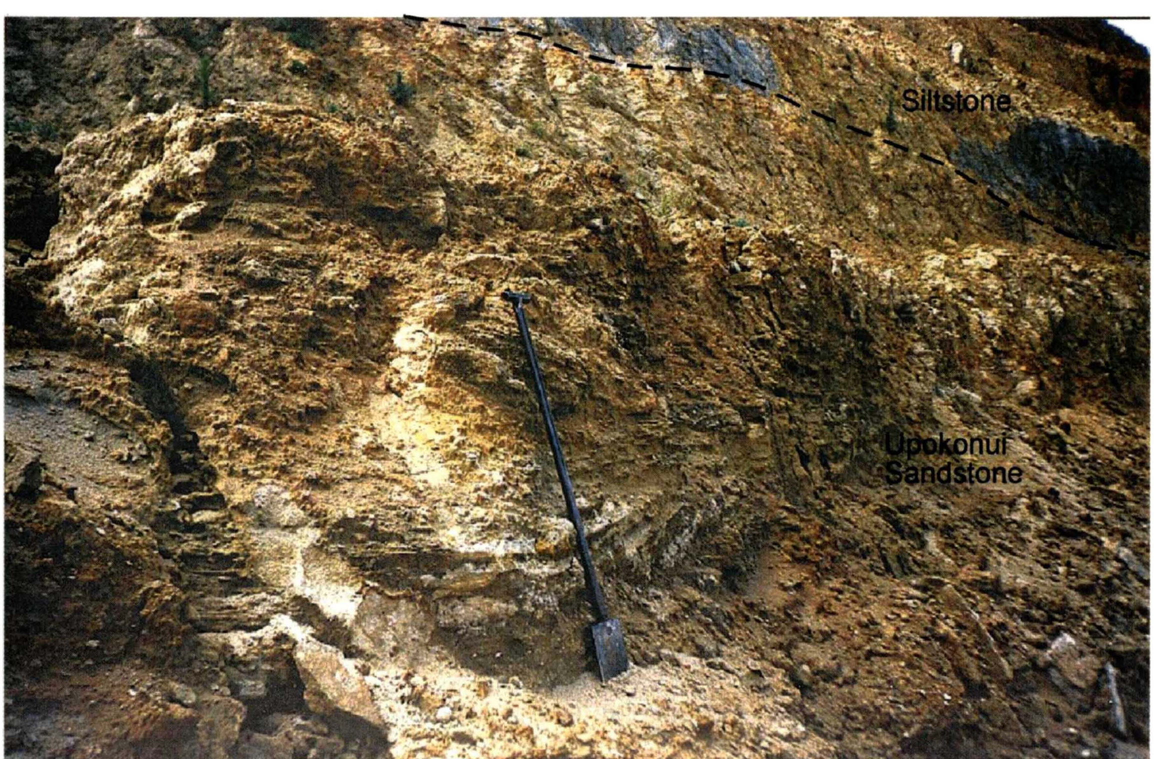

Figure 3.19: Top of Upokonui Sandstone at site 12 (Kuranui Quarry). Note trough cross-bedding and isolated, polyhedral concretions. Spade is 1.1 m in length.

CHAPTER FOUR:

CHRONOLOGY.

Introduction.

This chapter aims to define the bioevents associated with the beginning and end of the Mangapanian Stage, and to integrate these biostratigraphic datums with the results of numerical dating to provide an integrated chronology for this stage. The biostratigraphic datums investigated here are chiefly derived from fossil molluscs, with foraminiferal bioevents also included when possible. Numerical age determinations are mainly based on magnetostratigraphy, with particular focus on the Gauss/Matuyama paleomagnetic transition occurring at 2.582 Ma (Lourens *et al.,* 1996). Radiometric dating of several rhyolitic tephras within the Pliocene part of the Wanganui Basin succession has provided ages which allow the magnetostratigraphy for the Wanganui sections to be related to the Geomagnetic Polarity Timescale (GPTS).

Because no single section contains all the relative and absolute age datums identified within the Mangapanian Stage, stratigraphy and mapping provide the framework for the integrated chronology. This is facilitated by the many shellbeds within Mangapanian strata in the western part of the basin. The shellbeds, particularly those comprising the transgressive systems tracts (TSTs), enable subdivision of the strata into (easily) mappable horizons of regional extent. Considerable emphasis has been placed therefore on accurate correlation of shellbeds between sections (Chapter 3).

The use of the Mangapanian Stage as a stratigraphically useful biozone is restricted to New Zealand strata only, and reflects the isolation of the New Zealand Subcontinent from the natural processes and climatic variations which occurred elsewhere on the earth during the Pliocene and drove faunal changes. The relationship between the "Mediterranean" (International) Stages (e.g. Piacenzian, Gelasian, Calabrian) and the New Zealand Regional

Stages is shown in figure 4.1. The most recent study involving the chronostratigraphy of Wanganui Basin (and New Zealand stage system) reiterates the necessity of maintaining a biostratigraphic basis for stage subdivision (Beu, 2001), a paradigm that is continued in this study.

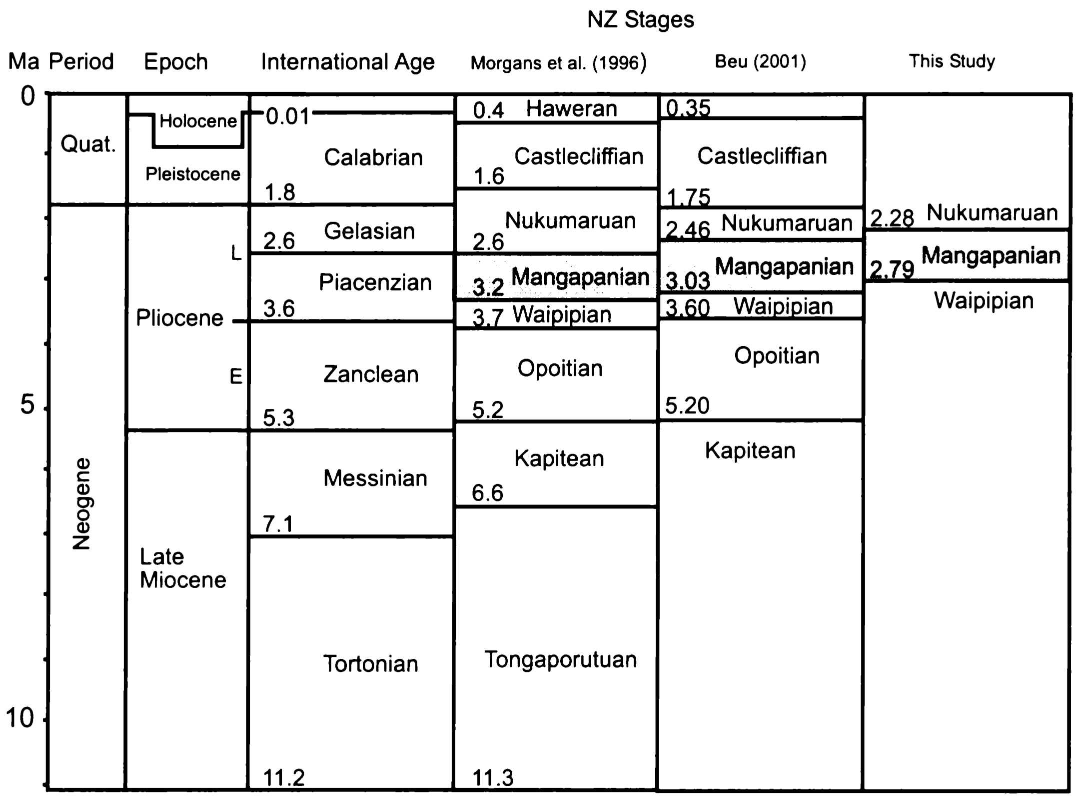

Figure 4.1: International and New Zealand late Cenozoic timescales showing published ages of Mangapanian Stage. after Berggren *et al.*, (1995), Morgans *et al.*, (1996) and Beu (2001).

As originally defined by Fleming (1953, p. 102), the Mangapanian Stage refered to the stratigraphic interval between the base of the Mangapani Shell Conglomerate and the base of the Hautawa Shellbed. Beu (2001) proposed that the basal Mangapanian SSP (standard section and point) be located at the base of the Mangapani Shell Conglomerate at its type locality, in the Waitotara River valley. This practice is supported here, because of the many bioevents occurring at this horizon, especially the *Phialopecten marwicki – Phialopecten thomsoni* speciation event, as described in Beu (1995). Similarly, the basal Nukumaruan SSP proposed by Beu (2001) at the base of the Hautawa Shellbed at the type locality on Old Hautawa (West) Road in the Porewa valley is supported here, as the multiple bioevents identified by Fleming (1953) at this horizon are still valid. One point of note is that none of the molluscan or foraminiferal bioevents occurring at either of these two localities are known to be concurrent with event horizons outside of the New Zealand subcontinent.

Current age estimates for the Mangapanian Stage.

This study is possibly the first to attempt to date Mangapani Shell Conglomerate itself, and thus the base of the Mangapanian Stage as originally defined by Fleming (1953), using modern dating techniques. The currently published age of 3.03 Ma for the base of the stage (Carter & Naish, 1998) assumes a correlation between the shellbed and the coiling change of *Globorotalia crassaformis* (Hornibrook, 1981). Carter & Naish (1998) based the assumption on Wilson (1993) who reported the first occurrence of dextrally coiled *Globorotalia crassaformis* at the top of the Kaena subchron in Wanganui Basin. (The age of the top of the Kaena subchron is derived from Lourens *et al.* (1996) at 3.032 Ma). However, it has not been demonstrated that the first occurrence of dextral *G. crassaformis* coincides with the original molluscan bioevents of Fleming (1953), on which the stage boundary was established. This requires physical correlation between the shallow-water sections containing the key molluscan bioevents and the deeper-water sections (e.g. Wanganui River) that contain the key formainiferal bioevents and retain a magnetostratigraphic signal.

Prior to this study, the age estimate for the top of the Mangapanian Stage was 2.46 Ma, based on the assumption that the Hautawa Shellbed (basal Nukumaruan Stage) is three 41 k.y. ^{18}O obliquity-controlled sequences above the Gauss/Matuyama paleomagnetic reversal which coincides with the glacial peak of Oxygen Isotope Stage 104 (Naish *et al.,* 1996; Beu, 2001). The current estimate for the Gauss/Matuyama reversal is 2.582 Ma (Berggren *et al.,* 1995; Lourens *et al.,* 1996).

This study has re-evaluated the existing data upon which the current ages of the Late Pliocene Wanganui Basin succession are based, and much new data has been generated. A description of the techniques involved in the numerical age determinations and their results follows in the numerical dating methods section.

Relative Dating (Biostratigraphy).

Note: FO = First known Occurrence in Wanganui Basin, unless otherwise stated.

LO = Last known Occurrence in Wanganui Basin, unless otherwise stated.

Wp-Wm = Waipipian-Mangapanian Stage boundary.

Wm-Wn = Mangapanian-Nukumaruan Stage boundary.

Foraminiferal datums:

Much work has been undertaken on the foraminiferal content of Wanganui Basin strata. The first major study was that of Wheatley (1943). He examined the foraminiferal content of beds at ~3 m intervals in the Rangitikei River valley, and at ~15 m intervals for the pre-Castlecliffian strata in the Turakina and Wanganui River valleys. This was the first major attempt to subdivide these sections into biostratigraphic zones, and these data remain useful some 60 years later. Some planktic foraminiferal census data for strata in the upper Waitotara valley were reported by Jenkins (1971), but these three samples did not allow many conclusions to be drawn. However, Hornibrook (1981) re-evaluated these samples, and compared them with data from the East Coast sections of similar age. Collen (1972) conducted a detailed study of the Wanganui Basin foraminifera, with detailed census of many samples from the Waverley Beach, Wilkies Bluff, Waitotara valley, Wanganui River, Rangitikei River, Watershed and Saddle Road Sections. That study placed particular emphasis on planktic foraminifera where possible in the recognition that their bioevents are not facies-controlled, and probably occur synchronously over much of the South Pacific ocean at similar latitudes. A suite of paleomagnetic samples collected in the Turakina valley by McGuire (1989) has also been picked for foraminifera by R. H. Hoskins (then of Geological Survey, DSIR), and the main biostratigraphic datums published in McGuire (1989). Journeaux (1995) (also published in Kamp *et al.* (1998)), studied foraminifera from the Rangitikei River valley near Mangaweka, and investigated trends in various parameters revealed by foraminiferal censuses of 116 samples through the Utiku Subgroup and Mangaweka Mudstone Formation. The most recent large-scale study involving foraminiferal biostratigraphy within the basin is that of Hayton (1998) who undertook foraminiferal censuses on approximately 100 samples collected between Tieke and Te Rimu in the Wanganui River valley. Particular emphasis was placed on planktic foraminifera, in order to establish a firm biostratigraphy for the section.

A common problem revealed by all of the above studies is the low foraminiferal content within the sediments, which is probably a result of both a high rate of terrigenous sediment accumulation, meteoric dissolution of carbonate in the shallow subcrop, and outcrop weathering. Benthic foraminifera dominate the foraminiferal fossil assemblages within the succession, with planktic species forming less that 1% of the total population of most samples. The highest measured percentage of planktics compared with benthics for Wanganui Basin is 36% planktic (Collen, 1972).

Benthic foraminifera:

Very few benthic foraminiferal bioevents associated with either the Wp-Wm or Wm-Wn Stage boundaries have been identified in Wanganui Basin, the only notable exception being the LO of *Cibicides molestus,* which has been traditionally used as a proxy for the Wp-Wm Stage boundary since Collen (1972), who located it in the Rangitikei and Wanganui valleys. Subsequently, this datum has been located in the following sections: Rangitikei valley (Journeaux, 1995), Turakina valley (Hoskins in McGuire, 1989), Whangaehu valley (this study) and Wanganui valley (Hayton, 1998). This datum appears to have been also noticed by Wheatley (1943), with correlation lines drawn between the Rangitikei, Turakina, Mangawhero and Wanganui River valleys at the same stratigraphic height as more recent workers (figures appear in Feldmeyer *et al.,* 1943). Hornibrook (1989, p.80) noted that while the LO of *C. molestus* approximates the Wp-Wm boundary, it remained unreliable, as it had not been firmly related to Fleming's (1953) original molluscan definitions of the stage boundary. Hornibrook (1989) suggested an end Waipipian LO of *Saracenaria italica,* and data from Hayton (1998) supports this, with the LO of *C. molestus* occurring at the same stratigraphic height as the LO of *S. italica* in the Wanganui River valley section.

The only reliable benthic foraminiferal bioevent marking the Wm-Wn Stage boundary appears to be the FO of *Rotalia wanganuiensis,* from data in Naish (1996), and McIntyre (1997) for the Rangitikei and Wanganui River valley sections respectively.

Planktic foraminifera:

While planktic foraminiferal bioevents are generally regarded as being more reliable datums than their benthic equivalents, the scarcity of planktic formainifera in Wanganui Basin sediments makes their biostratigraphy a difficult procedure. The two main planktic bioevents associated with the Mangapanian Stage that have been located stratigraphically are the FO of dextrally coiled *Globorotalia crassaformis* in the late Waipipian, and the FO of *Globorotalia crassula* at the Mangapanian-Nukumaruan stage boundary. While *G. crassaformis* has been collected from strata in the Rangitikei (re-evaluation of mounted samples from Journeaux (1995) by M. Crundwell), Turakina (Hoskins in McGuire, 1989), Wanganui (Collen, 1972; Hayton 1998) and Waitotara (Jenkins, 1971; Collen, 1972) river valleys, sufficient numbers of specimens were collected only by Hoskins (in McGuire, 1989) and Hayton (1998) across the sinistral to dextral transition zone to locate the bioevent accurately. In all cases, the FO of dextrally coiled *G. crassaformis* is several hundred metres below the LO of *Cibicides molestus.* This is opposite to the relative positions established by Hornibrook (1981) in contemporaneous East Coast strata. However, Hornibrook (1981, p. 270) mentions that the LO of *C. molestus* in the East Coast Mangaopari Stream section is probably due to facies control, not its actual extinction. The stratigraphic distance between the two datums in Wanganui Basin is 210 m (Rangitikei valley), 338 m (Turakina valley) and 158 m (Wanganui valley).

Planktic foraminiferal bioevents occurring at the Wm-Wn stage boundary are represented by the FO of *Globorotalia crassula* and *Globorotalia truncatulanoides.* The only earliest Nukumaruan record of *G. crassula* in Wanganui Basin is in a single sample from the upper part of the Hautawa Shellbed in the Mangawhero River valley (Hornibrook, 1981). Collen (1972) records the FO of *G. truncatulinoides* in the early Nukumaruan in the Rangitikei River valley, 45 m above the Hautawa Shellbed, but considerable uncertainty exists as to the evolutionary relationship between *G. tosaensis* and *G. truncatulinoides,* so this is not regarded as a reliable biostratigraphic datum (Hornibrook, 1989).

Molluscan bioevents:

(Photographs of some biostratigraphically useful fossil molluscs are presented at the end of this chapter)

The richly fossiliferous Wanganui Basin strata comprise the original type area for the molluscan definition of the New Zealand Late Pliocene geological timescale, both of the Wp-Wm and Wm-Wn stage boundaries. These early studies are outlined in Chapters 3, 5 and 6, with the most notable papers being Laws (1940), Fleming (1953), Carter (1972) and Beu (1995). One limitation of using fossil molluscs for Wanganui Basin biostratigraphy is facies control on their distribution. Most fossil molluscs occur only in shellbeds, which recur at repetitive ~30 to ~40 m intervals in the cyclothemic strata. The massive mudstone or sandstone units forming the bulk of the thickness of sequences are barren of macrofossils. Thus, the location of any stage boundary is potentially imprecise, as the bioevents that mark the stage boundary did not necessarily occur while shellbed accumulation took place, and thus stage boundaries could either be placed at the base of the shellbed containing the first occurrence of a new species, or at the top of the preceding shellbed in which the last occurrence of an earlier species occurs. However, the Wp-Wm and Wm-Wn Stage boundaries are placed at the base of the Mangapani Shell Conglomerate and the Hautawa Shellbed respectively, as these stage boundaries are both mainly based on first occurrences (e.g. *Phialopecten thomsoni* and *Zygochlamys delicatula,* respectively), on evolutionary intermediate populations (e.g. *P. thomsoni* in Mangapani Shell Conglomerate), or on the dual occurrence of last and first occurrences of some species within a single shellbed (e.g. LO *Crassostrea ingens* and FO *Z. delicatula*, lower Hautawa Shellbed). Unfortunately, the lower part of the Mangapanian strata is generally unfossiliferous, with the only exception being the Mangapani Shell Conglomerate itself. Thus, some bioevents for the Mangapanian Stage are not well represented in Wanganui Basin, including those unsuited to the facies making up the Mangapani Shell Conglomerate. Examples include the first known local occurrence of *Aoteadrillia alpha, Alcithoe brevis,* and the genus *Talabrica,* all of which have not been located any earlier than the mid-Mangapanian (Wilkies, Te Rama, and Hautawa Shellbeds, respectively). The molluscan biostratigraphic ranges relevant to the Mangapanian Stage are shown in Figure 4.2.

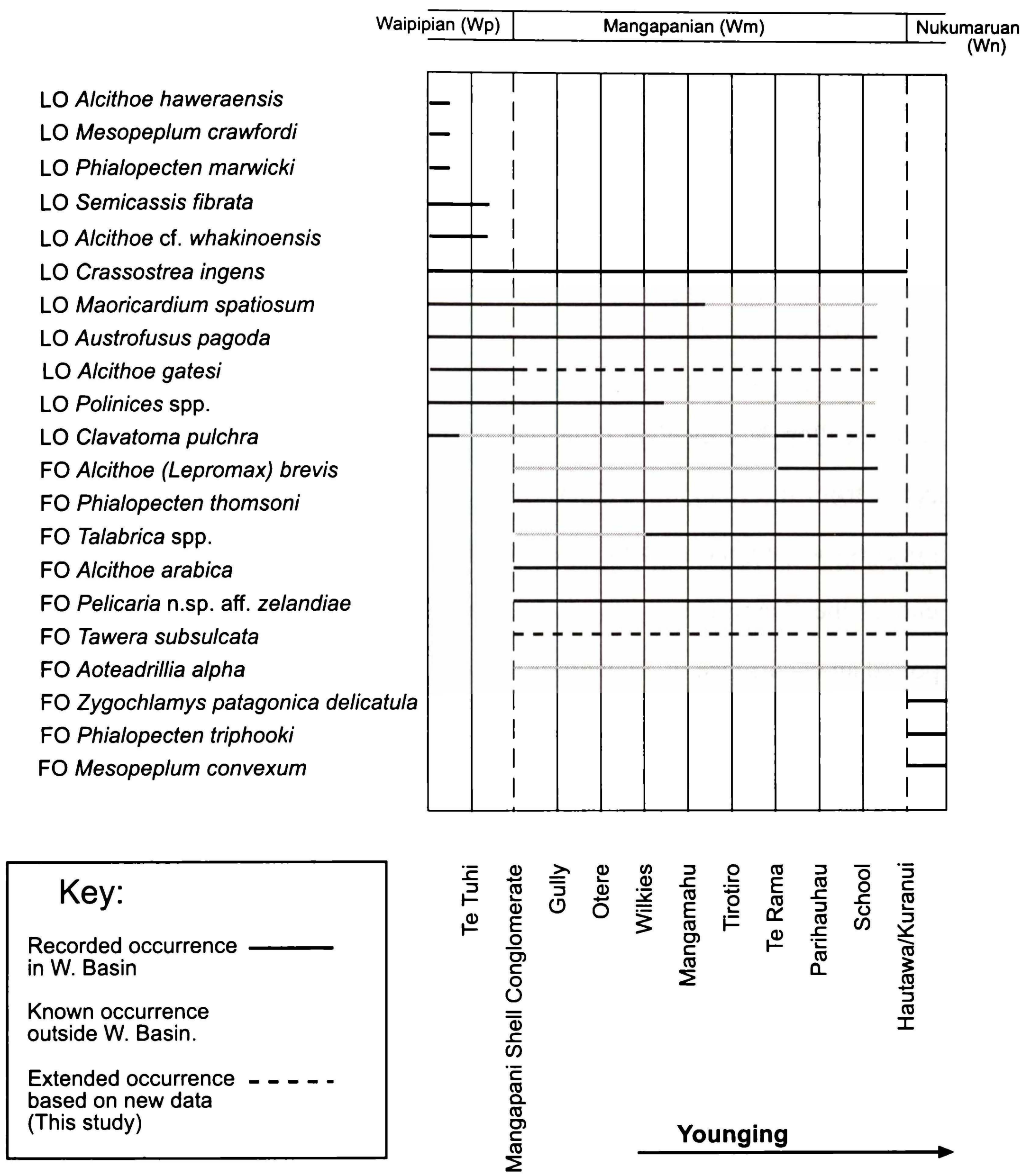

Figure 4.2: Molluscan bioevents associated with the Mangapanian Stage, based on collections made in this study. Note the subdivision of the stage into shellbeds, which reflects the variable stratigraphic occurrence of fossil molluscs within the stage.

Waipipian-Mangapanian Stage datum:

The Waipipian-Mangapanian Stage boundary is considered to coincide with an abrupt cooling of sea temperatures surrounding the New Zealand subcontinent. It is marked by the extinction of 14.2% of local molluscan genera, the numbers falling from 289 to 257 (Beu, 1990).

The LO of the scallop *Mesopeplum crawfordi* occurs within the Waipipian Stage, and has been collected from the Rangitikei (Journeaux, 1995) and Waitotara valleys, but in both sections it occurs too far beneath the known Wp-Wm boundary to be regarded as concurrent with the end of the Waipipian (~ 100 m in Rangitikei, ~ 500 m in Waitotara). Fleming (1953) reported an occurrence of *Semicassis fibrata* in the Te Tuhi Shellbed (~ 110 m below the Mangapani Shell Conglomerate in the Wanganui River section). This species is not known after Waipipian time in Wanganui Basin. *Alcithoe* cf. *whakinoensis* was also collected from this locality during fieldwork for this study, and is also not known to occur later than Waipipian in Wanganui Basin. Fleming (1953) recorded *Mesopeplum crawfordi* and *Phialopecten marwicki* from the Waipipi Beach section, but the exact stratigraphic relationships between that section and the Waipipian part of the Waitotara River valley section remain unknown.

In this study, most bioevents marking the Wp-Wm boundary are first occurrences, with the most notable being the evolutionary FO of the large scallop *Phialopecten thomsoni.* Furthermore, it is restricted to the Mangapanian Stage, making it particularly useful for relative dating. The best occurrences of *P. thomsoni* are in the Mangapani Shell Conglomerate in Waitotara valley, where it is abundant in the base of the upper part of the unit. Specimens from this locality have been examined by Beu (1995), and are of a transitionary form between *P. marwicki* and typical Mangapanian *P. thomsoni*, but are taxonomically closer to the later species. Thus, confidence can be placed in the base of the Mangapani Shell Conglomerate as an appropriate stage boundary, as originally defined by Fleming (1953), and endorsed by Beu (2001). *P. thomsoni* has been collected also from the

Mangapani Shell Conglomerate in an abandoned quarry near Waitotara township, on the Waitotara River valley roadside and at the type locality in Mangapunipuni valley. Other molluscan bioevents occurring at this horizon include the FO of the gastropod *Pelicaria* n.sp. aff. *zelandiae* which has been collected from the Mangapani Shell Conglomerate in the Wanganui River valley near Atene, and extends from the beginning of the Mangapanian Stage into the early Nukumaruan (Boreham, 1963). The FO of *Penion sulcatus* has also been located at this horizon, at the same locality. Beu & Maxwell (1990) placed the FO of the bivalve *Tawera subsulcata* at the Wm-Wn Stage boundary, but many specimens have been collected from throughout the Mangapanian succession, including the Mangapani Shell Conglomerate, as also listed in Fleming (1953). Fleming (1953) recorded the occurrence of *Alcithoe arabica* in the Mangapani Shell Conglomerate, which is also its first known occurrence in Wanganui Basin.

Other molluscs that are considered to appear at the beginning of Mangapanian time based on their occurrences outside Wanganui Basin are *Aoteadrillia alpha, Alcithoe brevis,* and the genus *Talabrica,* but these have not been collected from strata older than mid-Mangapanian in the present study.

Mangapanian-Nukumaruan Stage datum:

Beu (1990) states that 5% of New Zealand molluscan genera became extinct at the end of the Mangapanian, but the arrival of subantarctic taxa boosted the number of genera from 257 in the Mangapanian to 312 in the Nukumaruan.

The most famous molluscan bioevent synonymous with the base of the Nukumaruan Stage in Wanganui Basin is the FO of the scallop *Zygochlamys delicatula,* which was first pointed out by Fleming (1944). However, Fleming did not name the unit from which Feldmeyer *et al.* (1943) collected this specimen, naming it in his more substantiative "The Geology of Wanganui Subdivision", published in 1953. This work reported the occurrence of *Z. delicatula* within the Hautawa Shellbed at its type section on the Rangitikei-Turakina watershed westward to the interfluve between the Mangawhero River and the Upokonui

Stream. McIntyre & Kamp (1998) collected it from the Hautawa Shellbed at Parikino in the Wanganui River valley, and during fieldwork for this study, it was collected from the same horizon in the Kauarapaoa valley. To the east of the type locality, *Z. delicatula* has been recovered from both the Hautawa Shellbed and Tuha Shellbed at localities in the banks of the Rangitikei River (Naish & Kamp, 1995), and in the Pohangina valley by Carter (1972) in the Hautawa Shellbed, Tuha Shellbed and Piripiri Limestone.

The earliest record of the early Nukumaruan restricted scallop *Phialopecten triphooki* in Wanganui Basin was made by Fleming (1953), who collected it from the Hautawa Shellbed at two localities: the type section on Old Hautawa Road; and at a locality near Parihauhau Road. Fleming also noted its occurrence in the Kuranui Limestone near Okiwa. However, Fleming (1953) did not differentiate *P. thomsoni* from *P. triphooki.* Beu (1978; 1995) has re-evaluated and confirmed that the specimens from the Hautawa Shellbed are *P. triphooki* and distinct from *P. thomsoni. P. triphooki* has been collected from the Kuranui Limestone in this study, confirming its suspected Nukumaruan age. Carter (1972) also reported the FO of *P. triphooki* in his "Basal Conglomerate" (confirmed as Hautawa Shellbed in the present study) in Pohangina valley, on the eastern Wanganui Basin margin.

The FO of the scallop *Mesopeplum convexum* appears to be located in the Hautawa Shellbed and Kuranui Limestone, collected in this study from from several localities (Pohangina, Rangitikei, Mangawhero, and Wanganui sections, and at Windy Point Quarry near Okiwa). Fleming (1953) collected *M. convexum* from the Kauarapaoa valley, but uncertainty exists as to the exact location of the collection site, which is not now exposed, and could either correspond to the School (Wm) or Hautawa shellbeds (Wn), as very little stratigraphic distance separates the two shellbeds in this section.

The extinction of the giant oyster *Crassostrea ingens* occurred during earliest Nukumaruan time, as it is found in the lower part of the Hautawa Shellbed in numerous localities across Wanganui Basin. Thus an overlap of the FO of *Zygochlamys delicatula* (and / or *Phialopecten triphooki*) and the LO of *Crassostrea ingens* is a useful overlap zone which helps identify the earliest part of the Nukumaruan Stage (presumably first < 20 k.y.) in otherwise problematic units such as the Kuranui Limestone and the "Basal Conglomerate" of Carter (1972). Both of these units contain *C. ingens* together with either *P. triphooki* and / or *Z. delicatula,* thus confirming an earliest Nukumaruan age for each unit.

Other known last occurrences marking the end of the Mangapanian Stage are the LO of *Phialopecten thomsoni* and *Alcithoe gatesi,* both of which last occur in the School Shellbed in the Kauarapaoa and Wanganui River sections. Beu & Maxwell (1990) place the LO of *A. gatesi* at the end of the Waipipian Stage, but the specimen from the School Shellbed (late Wm) is confirmed as *A. gatesi* (A. Beu, pers. comm.).

Despite suitable facies, some last occurrences of molluscs have not been located particularly close to the Mangapanian-Nukumaruan Stage boundary, where they would be predicted to occur slightly below the Hautawa Shellbed. However, their occurrence is useful, as they confirm their presence within the Mangapanian Stage. These include *Polinicies* (s.s.) (Wilkies Shellbed), *Clavatoma pulchra* (Mangapani Shell Conglomerate) and *Maoricardium spatiosum* (Mangamahu Shellbed). Figure 4.2 shows the molluscan biostratigraphy relevant to the Mangapanian Stage.

Numerical Dating.

Radiometric techniques on tephras:

Radiometric dating techniques are not particularly applicable to Mangapanian strata in Wanganui Basin, as juvenile dateable material from beds is rare, is not located proximal to the stage's boundaries, and the results have low precision. Only three Mangapanian tephras have been identified, with one (the Otere Tephra) discovered during fieldwork for this study in the Kauarapaoa valley, and two being found by Journeaux *et al.* (1996) near Mangaweka in the Rangitikei River valley. These latter two are the Eagle Hill and Kowhai Tephras, which are separated by only a few metres of Mangaweka Mudstone, meaning that they accumulated within several hundred years of each other. This reduces their combined usefulness to essentially a single potential age, as the uncertainty associated with the mean ages will overlap. Two techniques were used to date these tephra radiometrically: SHRIMP based U-Pb, and single crystal U-Th/He dating of zircon.

SHRIMP U-Pb Dating:

For this study, the Otere and Eagle Hill Tephras were dated using the U-Pb technique at the University of Western Australia by SHRIMP (Sensitive High Resolution Ion Microprobe) to measure the amount of U-Pb decay in zircon crystal separated from each tephra. The results are based on relatively few replicates, because of the low number of juvenile zircons compared with detrital, significantly older zircon crystals contaminating the sample, probably as a result of bioturbation of the tephra following deposition. The age determined for the Eagle Hill Tephra was based on five measurements from five separate zircons, while only two young zircons were probed in the Otere Tephra, with one zircon subjected to two analyses, for a total of three measurements.

(Data corrected for U-Th disequilibrium)

Otere Tephra: 2.80 ± 0.10 Ma (n=3)

Eagle Hill Tephra: 2.94 ± 0.15 Ma (n=5)

However, the correction for U-Th disequilibrium is probably not necessary (Dr Stuart Brown, pers. comm., Dec. 2000), which means that the ages given below are probably more accurate and representative, despite having a lower precision:

(Data uncorrected for Th-U disequilibrium)

Otere Tephra: 2.71 ± 0.25 Ma (n=3)

Eagle Hill Tephra 2.85 ± 0.20 Ma (n=5)

The low number of juvenile zircon crystals suitable for analysis means that the ages lack good precision. However, the results are useful as a method of matching the magnetostratigraphy with the Geomagnetic Polarity Timescale (GPTS), as described below.

Single Crystal U-Th/He Dating:

Zircon crystals separated from the Otere and Eagle Hill Tephras were dated using the U-Th/He technique at the California Institute of Technology (CalTech). No juvenile crystals were analysed in the Eagle Hill Tephra, so the age of this tephra could not be determined by this method. However, three juvenile zircon crystals from the Otere Tephra were measured, with the corrected results being: 2.57 ± 0.04 Ma, 3.63 ± 0.04 Ma and 3.67 ± 0.19 Ma. Since only the youngest age overlaps with the SHRIMP ages, this date is regarded as being representative of the age of the tephra. The two relatively older dates possibly resided in a magma chamber for ~ 1 M.y. before eruption, and thus do not reflect the true eruptive ages.

Paleomagnetism.

Many studies investigating the paleomagnetic properties of Wanganui Basin strata have been conducted, with several including Mangapanian strata. Early attempts to measure the magnetic properties of Pliocene strata were unsuccessful, as the magnetic signal was too weak to be measured with spinner magnetometers. The first attempt was made in Feburary 1970 by N.D. Watkins and J.P. Kennett, who collected paleomagnetic samples from Wanganui River valley and the Pleistocene succession on the coast. No publications arose from their work on Wanganui Basin samples. The first successful paleomagnetic investigation within the basin was made by Seward *et al.* (1986), who produced a magnetostratigraphy for the Rangitikei River valley. This study did reveal patterns in the magnetic polarity of the strata, but did not adequately show relations between the magnetostratigraphy, the GPTS and the lithostratigraphy, particularly in the Nukumaruan strata. However, this study revealed a pattern of reversed and normal polarity although the correlations with the GPTS have changed with more recent work The next major study was that of McGuire (1989), who determined the magnetostratigraphy of the Tangahoe Group

(Taihape) Mudstone in Turakina River valley. This study was integrated with new foraminiferal biostratigraphic data for the section, the first study to do so in Wanganui Basin. This was followed by Wilson (1993), who resampled the Rangitikei River section, and produced a provisional magnetostratigraphy for the Wanganui River section. Naish *et al.* (1996) integrated data from Wilson (1993), Pillans *et al.* (1994) and new data provided by Dr Brad Pillans (Australian National University) to produce a magnetostratigraphy for the Waipipian-Nukumaruan section in the Rangitikei River valley.

For the purposes of this study, a suite of paleomagnetic samples from 44 sites was collected from the succession exposed in the Wanganui River valley (24 sites), Rangitatau East Road at Paparangi (4 sites), Kauarapaoa valley (5 sites), Whangaehu River valley (4 sites) and Rangitikei River valley (7 sites). These samples were collected to help locate the position of the Gauss/Matuyama transition, as well as to add to new unpublished data in the Wanganui River valley, and to supplement existing data for the Rangitikei River valley section (Naish *et al.*, 1996). The magnetic properties of the samples were measured by the author and Dr Gillian Turner (Victoria University of Wellington) in late 1998 at the joint Australian Geological Survey / Australian National University laboratory in Canberra. Thermal demagnetisation was used in conjunction with a liquid helium cryogenic magnetometer to measure the magnetisation of the samples. Samples (four from each site) were demagnetised in decreasing increments up to 340°C, (0°C, 80°C, 120°C, 150°C, 180°C, 220°C, 250°C, 280°C, 300°C, 320°C, 340°C), at which temperature magnetic susceptibilities rose due to the formation of magnetite. The data was analysed using the methodology outlined in Turner (2001). Existing data from the Turakina River section (McGuire, 1989) and the Rangitikei, Turakina and Wanganui River sections (Wilson, 1993) have subsequently been reanalysed based on the new understanding of the origin of the magnetisation established by Dr G.M. Turner (Turner, 2001). These analyses have been carried out by Dr Turner and have been kindly made available for this study. The new data (declination, inclination) are reported in Appendix 3.

In the Rangitikei, Turakina and Wanganui River valleys, a new magnetostratigraphy is presented, in which a number of reversed and normal polarity chrons have been identified. Supplementary paleomagnetic polarity data from the Whangaehu, Kauarapaoa and Paparangi sections are also shown, to increase the resolution of the magnetostratigraphy in the Okiwa Subgroup, where the remnant detrital magnetisation is difficult to isolate. The magnetostratigraphy of these sections are illustrated in figures 4.3, 4.4, 4.5, 4.6, 4.7 and 4.8, together with the biostratigraphic datums and tephra ages, where applicable. These figures display the magnetostratigraphy on the left hand side of the lithological column, with the interpretation of these data in terms of the GPTS on the right side of each figure. For this study, GPTS ages from Lourens *et al.* (1996) are used, with the ages of the "X" cryptochron taken from Cande & Kent (1992; 1995). New data resulting from the present study has an "S" prefix.

Rangitikei River valley section:

The magnetostratigraphy of the Rangitikei River section is displayed in figure 4.3, together with a correlation to the GPTS. Correlation of the magnetostratigraphy in this section with the GPTS is facilitated by the occurrence of the Eagle Hill Tephra, which occurs almost precisely in the middle of the c. 450 m thick interval of Mangaweka Mudstone yielding normal polarity. The age of 2.85 ± 0.20 Ma determined in this study for this tephra allows a firm correlation to be made between this chron and the youngest normal interval of the Gauss chron (C2An.1n; 3.032-2.582 Ma). While the 95% confidence interval error on the age of the Eagle Hill Tephra does extend slightly above and below C2An.1n, the occurrence of the tephra in the middle of the chron lessens the likelihood of its measured age being outside this range. Thus, the paleomagnetic reversal near the top of the Mangaweka Mudstone in this section is almost certainly the Gauss/Matuyama (C2An.1n/C2r.2r) paleomagnetic reversal, which is has an age of 2.582 Ma. The two reversed samples from the upper part of the Utiku Subgroup are correlated with the Kaena subchron (C2An.1r; 3.116 to 3.032 Ma). Samples from the lower part of the Utiku Subgroup have normal polarities, which here are correlated with the middle part of the Gauss (C2An.2n) subchron.

A reversed interval within siltstone beneath the Utiku Subgroup is correlated with the Mammoth subchron, which extended from 3.330 Ma to 3.207 Ma. Separating the Kaena and Mammoth subchrons is the second normal polarity interval within the Gauss chron, C2An.2n, which is easily identifiable in all the three aforementioned sections, and occurred between 3.207 and 3.116 Ma. The lowermost normal polarity interval within the Gauss chron is C2An.3n, the base of which has an age of 3.596 Ma.

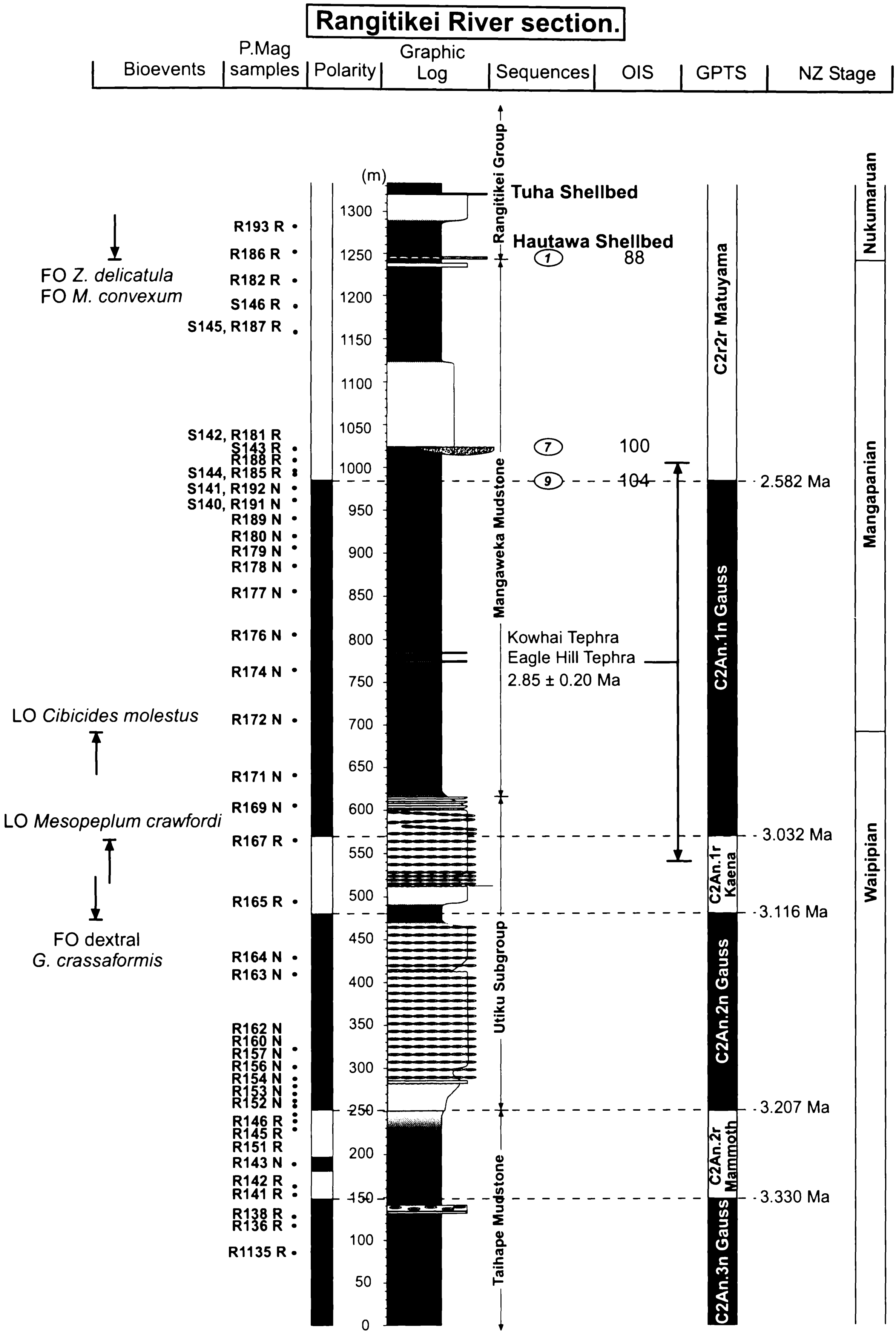

Figure 4.3: Chronology of Mangapanian Stage, Rangitikei River section. The lithologic column separates data on the left side of figure from the interpretation of that data on the right side. Note that Mangaweka Mudstone is extended to the base of the Hautawa Shellbed, including Mangarere Formation of Naish & Kamp (1995).

Turakina River valley section:

A robust magnetostratigraphy for the Turakina River valley section is available in the form of reinterpreted data from McGuire (1989) and Wilson (1993). Paleomagnetic samples with an "H" prefix on figure 4.4 are from the latter study; all others are from the former. While no radiometric ages are available for the stratigraphic interval displayed in figure 4.4, several bioevents also occurring within the Rangitikei River valley section permit correlation of the magnetostratigraphy for the section with the GPTS. In particular, the LO of *C. molestus* occurs in a long normal interval within the Mangaweka Mudstone in both these sections, and thus can be correlated with the youngest part of the Gauss chron, (C2An.1n; 3.032-2.582 Ma). This interpretation means that the paleomagnetic reversal observed near the top of the Mangaweka Mudstone is the Gauss / Matuyama (C2An.1n/ C2r.2r) transition occurring at 2.582 Ma. Above the G/M boundary, the Matuyama chron (C2r.2r) extends into the Okiwa Subgroup. However, a small reversed event occurring between shellbeds 4 (Te Rama) and 5 (Tirotiro) punctuates this interval, and is correlated with the "X" event cryptochron (C2r.2r-1) which current estimates place as occurring during the interval 2.420 to 2.441 Ma (Cande & Kent, 1992; 1995). A reversed interval within the upper part of the Utiku Subgroup is correlated with the Kaena subchron (C2An.1r; 3.116 to 3.032 Ma) within the Gauss chron, and the normal polarity interval within the lower part of the Utiku Subgroup correlates with the middle Gauss chron (C2An.2n), the base of which is co-incident with the base of the Utiku Subgroup, giving an age of 3.207 Ma.

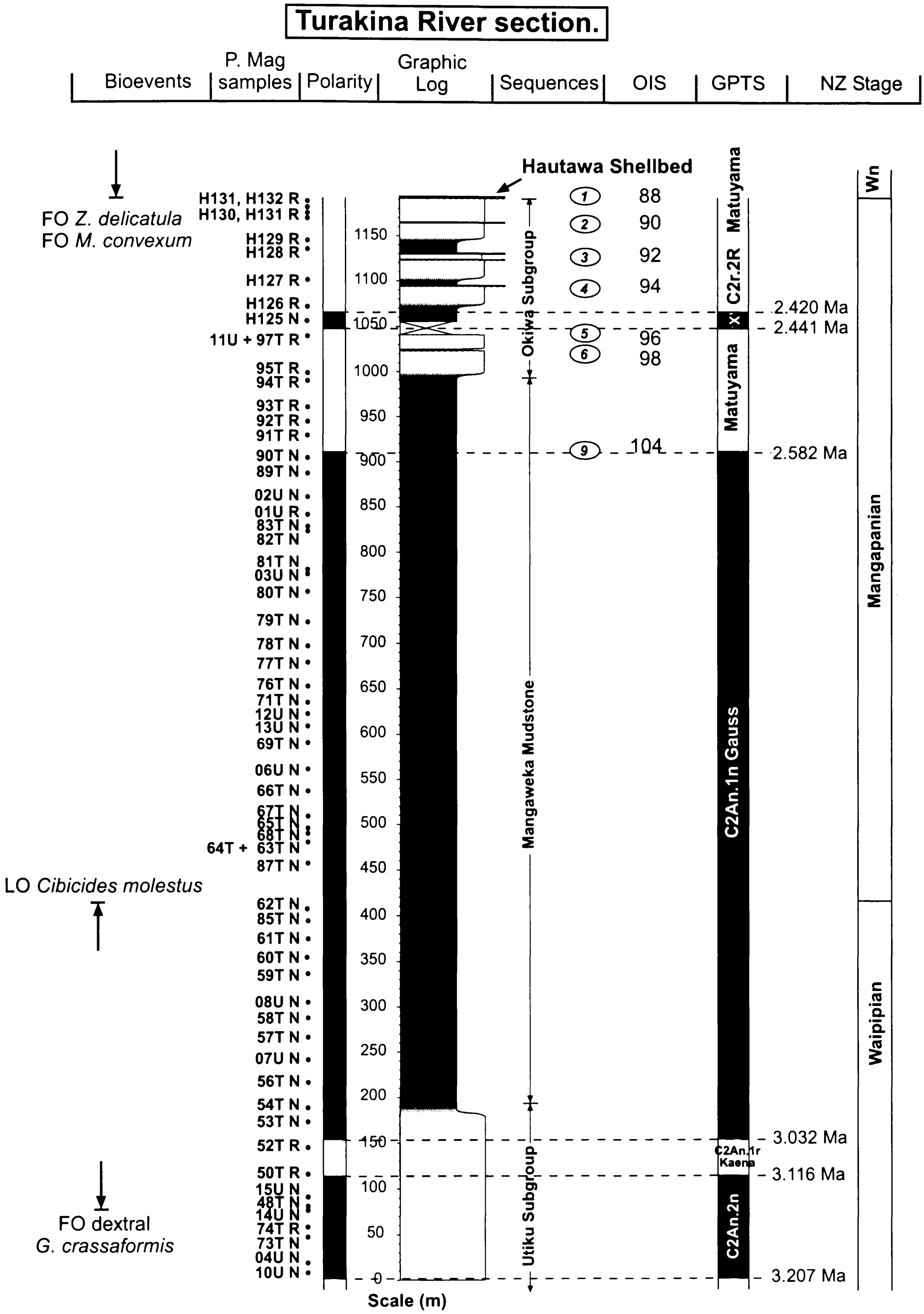

Figure 4.4: Chronology of Mangapanian Stage, Turakina River section. The lithologic column separates data on the left side of figure from the interpretation of that data on the right side.

Whangaehu River valley section:

Relatively little magnetostratigraphy is available for the Pliocene part of this section, with only 4 samples yielding polarities. The youngest three of these are reversed, and stratigraphically bracket the FO of *Zygochlamys delicatula* in the Hautawa Shellbed. In sections for which a more complete magnetostratigraphy is available, the Hautawa Shellbed occurs within the lower part of the Matuyama chron, and thus these three samples are correlated with the Matuyama chron. A single normal sample between the Tirotiro and Te Rama Shellbeds (shellbeds 4 & 5 on figure 4.5) occurs at the same stratigraphic height as a normal sample in the Turakina River valley section, and is thus correlated with the "X" event cryptochron (C2r.2r-1; 2.420 to 2.441 Ma) within the Matuyama chron (Cande & Kent, 1992; 1995).

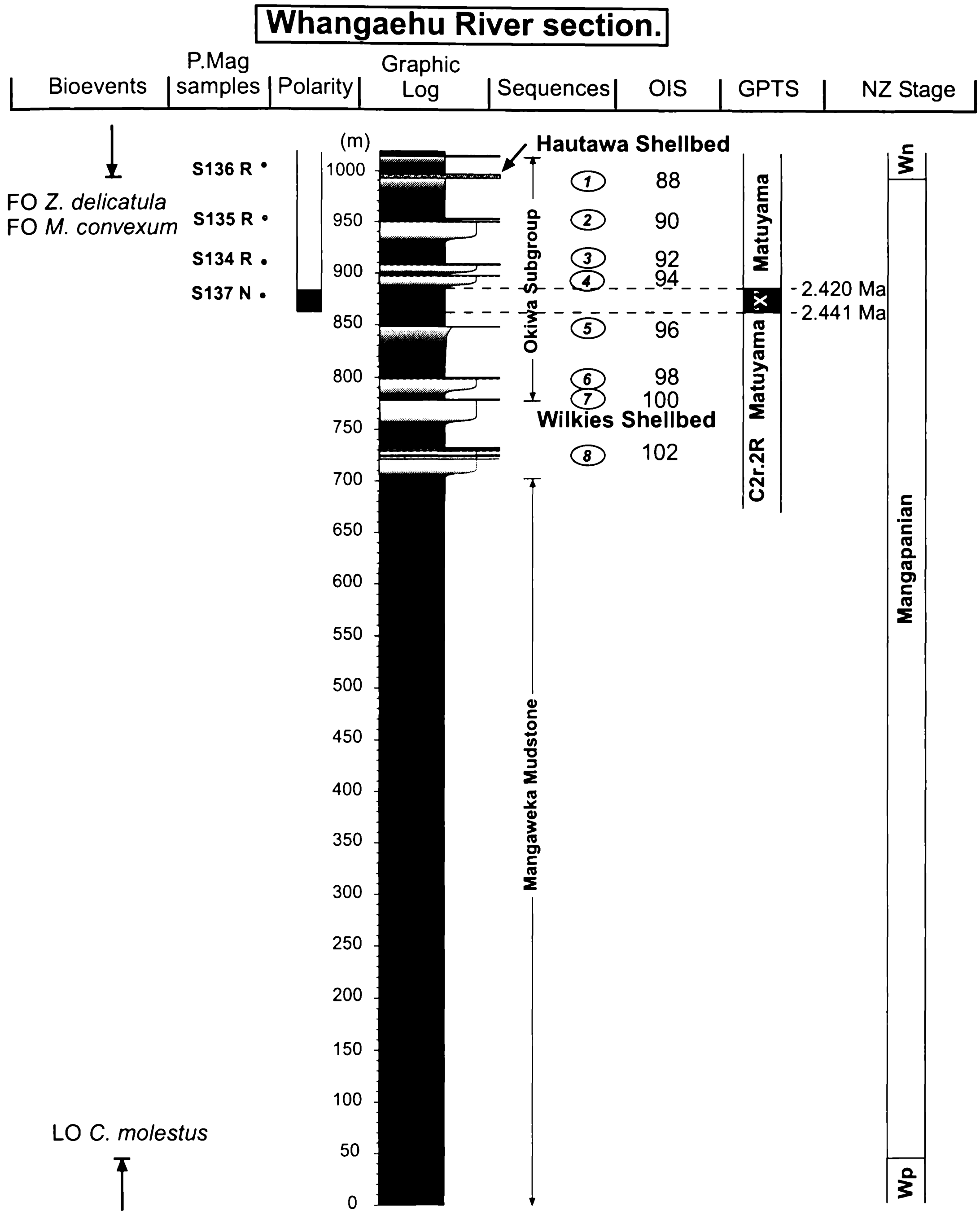

Figure 4.5: Chronology of Mangapanian Stage, Whangaehu River section. The lithologic column separates data on the left side of figure from the interpretation of that data on the right side.

Wanganui River valley section:

A magnetostratigraphy for part of the Wanganui River succession is presented in figure 4.6. The last occurrence of *C. molestus* once again lies within a thick interval of strata with normal polarities, allowing this interval to be correlated with the uppermost part of the Gauss chron (C2An.1n; 3.032-2.582 Ma). As illustrated in figure 4.6, strata within this interval includes the Mangapani Shell Conglomerate, and thus the magnetostratigraphy provides a coarse age constraint for the type unit of the base of the Mangapanian Stage. Two samples with reversed polarities immediately above the Koroniti Formation are correlated with the Kaena subcron (C2An.1r; 3.116 to 3.032 Ma), with the relatively thick normal interval including the Koroniti Formation correlated with the middle part of the Gauss chron (C2An.2n). Above the normal Gauss chron, reversely polarized strata of the Okiwa Subgroup are correlated with the lower part of the Matuyama chron (C2r.2r). The Gauss / Matuyama boundary (2.582 Ma) occurs a few metres below the top of the Mangaweka Mudstone in this section. While not identified in the magnetostratigraphy, the "X" event cryptochron is predicted to occur within siltstone between shellbeds 4 and 5, but this interval of strata cannot be sampled due to unsuitable facies, high degree of weathering, and poor accessibility. As shown on figure 4.6, the FO of dextral *G. crassaformis* occurs within C2An.2n, and the Mangapani Shell Conglomerate occurs within C2An.1n.

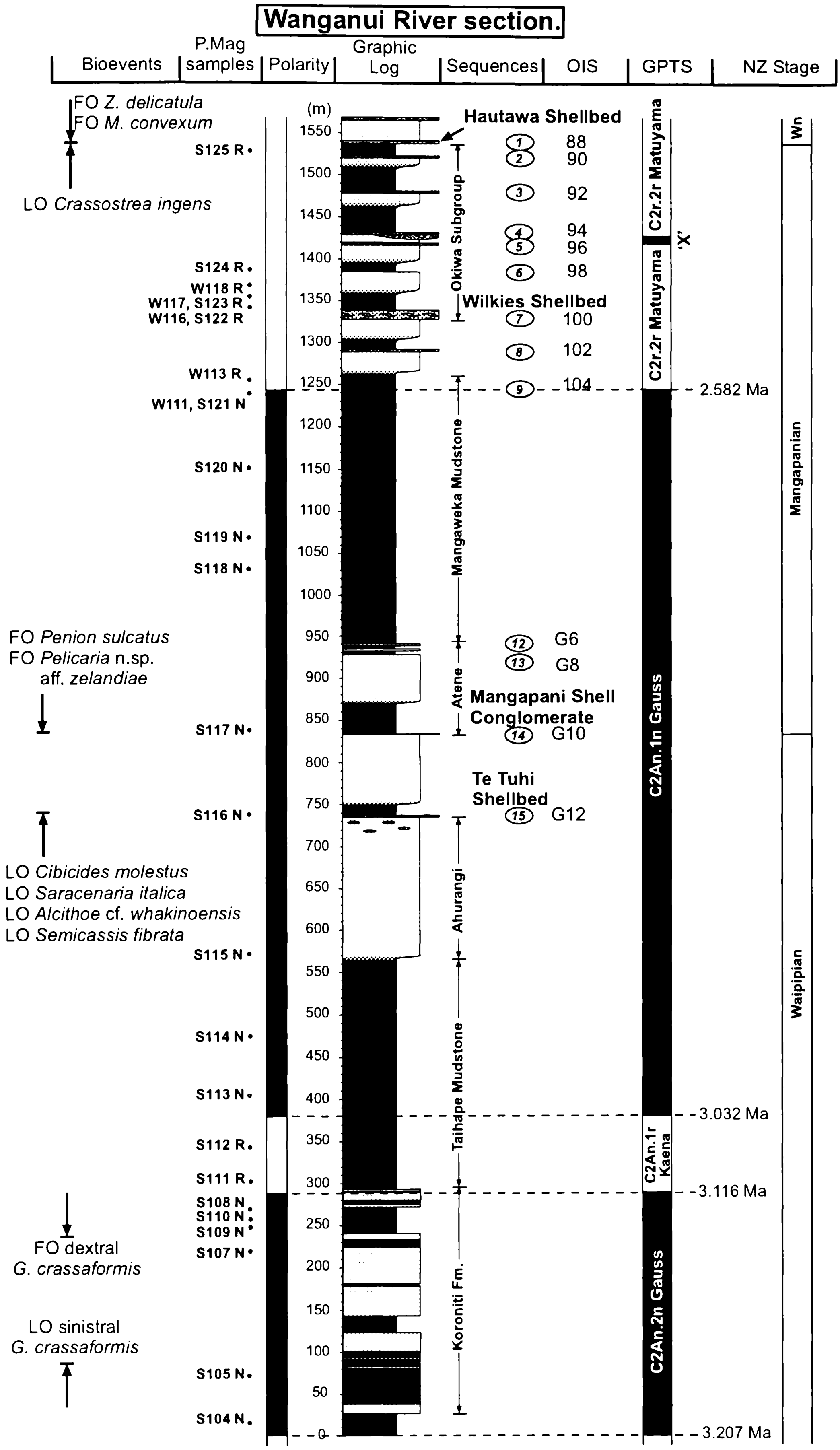

Figure 4.6: Chronology of Mangapanian Stage, Wanganui River valley section.

Kauarapaoa valley section:

A simple magnetostratigraphy for part of this section is presented in figure 4.7. The Otere Tephra provides a useful constraint for matching the magnetostratigraphy to the GPTS, as its age of 2.57 ± 0.04 Ma indicates a close match between the timing of the emplacement of the tephra and the Gauss / Matuyama reversal at 2.582 Ma. The low error associated with the age of the Otere tephra, indicated by error bars on figure 4.7, precludes the reversal event in the magnetostratigraphy from being the Gauss / Matuyama boundary, and thus it is probably the top of the "X" event cryptochron (C2r.2r-1), which has an age of 2.420 Ma (Cande & Kent, 1992; 1995). Furthermore, this normal sample occurs between shellbeds 4 and 5, matching the pattern observed in adjacent sections. This interpretation places the remaining three reversely polarised samples above the "X" event within the Matuyama chron (C2r.2r).

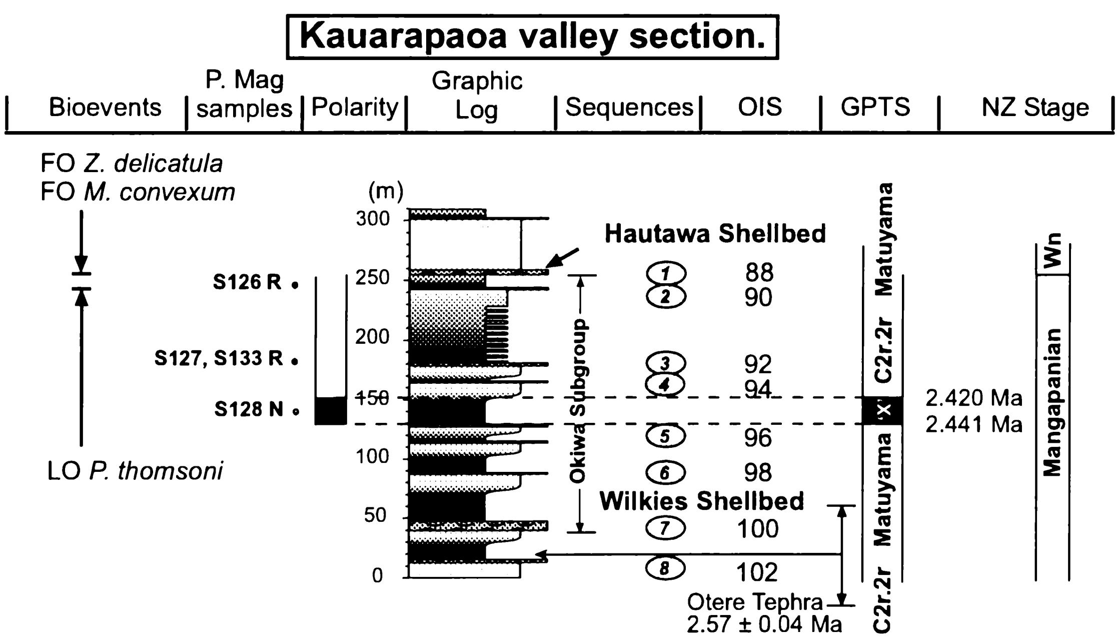

Figure 4.7: Chronology of Mangapanian Stage, Kauarapaoa valley section. The lithologic column separates data on the left side of figure from the interpretation of that data on the right side.

Paparangi section:

Figure 4.8 illustrates the magnetostratigraphy of the Paparangi section, determined from three sample sites. The simple R-N-R magnetostratigraphy of this section is correlated with the Matuyama chron (C2r.2r), bracketing the "X" event (C2r.2r-1), between shellbeds 4 and 5, mimicking patterns in the magnetostratigraphy of adjacent sections for this part of the Okiwa Subgroup.

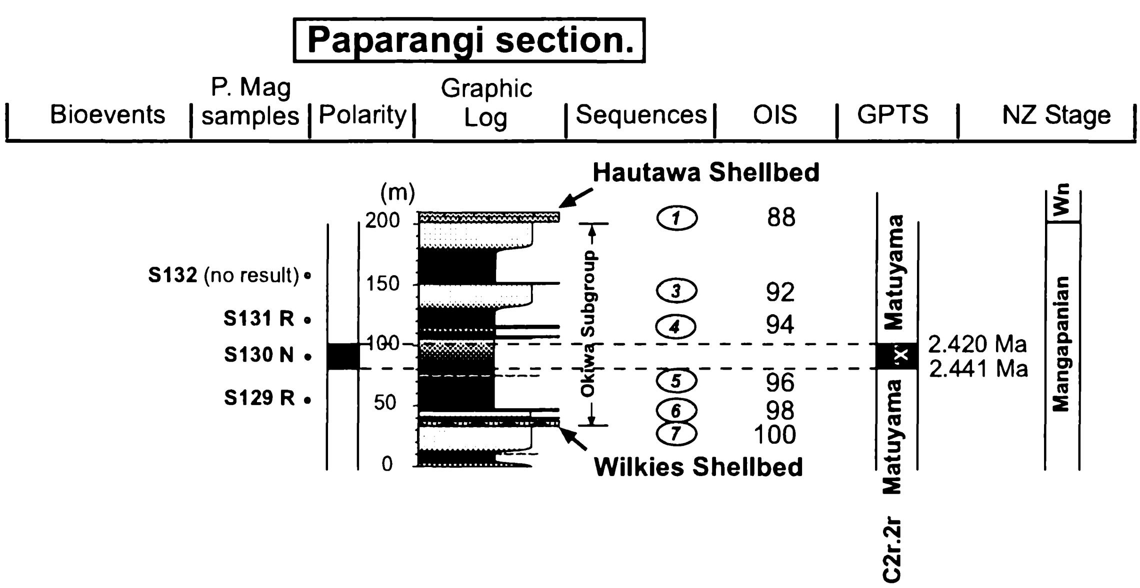

Figure 4.8: Chronology of Mangapanian Stage, Paparangi Section. The lithologic column separates data on the left side of figure from the interpretation of that data on the right side.

Paleomagnetic patterns:

Reversed polarities in strata within the upper Mangaweka Mudstone, the Okiwa Subgroup and Rangitikei Group have been correlated with the Matuyama chron in previous studies (Seward *et al.,* 1986; McGuire, 1989; Wilson, 1993; Naish *et al.,* 1996). This study confirms this correlation, based on the majority of samples collected from this interval having reversed polarities. The top of the Matuyama chron was not found in this study, as its age (0.78 Ma; Cande & Kent, 1995) puts it well outside the range of this study. Comparison of the position of the Gauss / Matuyama (C2An.1n / C2r.2r) paleomagnetic reversal within several sections reveals a generally regular stratigraphic distance between this paleomagnetic boundary and the Hautawa Shellbed. In the Rangitikei River section, the base of the Matuyama chron occurs 260 m stratigraphically below the Hautawa Shellbed. In the Turakina River section, this distance is 275 m, and in the Wanganui River section the distance is ~ 290 m. In all sections the G/M transition occurs in the uppermost part of the Mangaweka Mudstone.

The occurrence of the small normal paleomagnetic excursion in the early part of the Matuyama Chron (the "X" event cryptochron C2r.2r-1), provides a useful datum for correlation of strata between sections, and increases the level of chronological detail within the Okiwa Subgroup. The occurrence of this event between the Tirotiro Shellbed and Te Rama Shellbeds (shellbeds 4 and 5) in all three of these sections demonstrates the robustness of the original lithostratigraphic correlation of these units between the studied sections, and a comparison of the stratigraphic distance between the top of this cryptochron and the Hautawa Shellbed /Kuranui Limestone is useful. The stratigraphic distance between the Hautawa Shellbed /Kuranui Limestone and the top of the "X" event is 125 m in the Turakina River section, 105 m in the Whangaehu River section, 100 m in the Kauarapaoa Stream section and 100 m at Paparangi, but a substantial unconformity at the base of the Hautawa Shellbed / Kuranui Limestone makes measurements in the Kauarapaoa and Paparangi sections less meaningful. The consistency in the stratigraphic position of the normal event strengthens its credibility, and thus it can be used to date the strata in sections where it has been located. Furthermore, the "X" event has not been located in the Wanganui and Rangitikei River sections, but this is expected because of lack of sampling in the correct stratigraphic position in both sections. In the Wanganui River section the siltstone between the Tirotiro and Te Rama Shellbeds (shellbeds 4 and 5) has not been sampled for paleomagnetic determination, and in the Rangitikei River section no paleomagnetic data exists for strata immediately above the Mangarere Sandstone where it is expected that the "X" event should occur.

Beanland (1995) presented paleomagnetic data from a Nukumaruan mudstone unit in the vicinity of Saddle Road (near the Manawatu Gorge, south-eastern Wanganui Basin), which has a uniformly reversed polarity, placing it within the Matuyama chron. The data is of limited usefulness in this study because all samples were reversely polarised. However, the lack of normal polarities combined with biostratigraphic data constrain it to the early-mid Nukumaruan. While the data from Beanland (1995) is not included in this study, it nonetheless supports the positioning of the Nukumaruan Stage within the Matuyama chron.

Beneath the Matuyama chron, the position of the Mangapani Shell Conglomerate and the correlative LO of *Cibicides molestus* within the Gauss chron can be dated by interpolation of ages to strata occurring between the beginning and end of the upper Gauss chron (C2An.1n). Using ages of 3.032 and 2.582 Ma for the start and end of this chron (Lourens *et al.,* 1996), and assuming a constant rate of sediment accumulation between these ages gives an age of 2.79 Ma by interpolation for the Mangapani Shell Conglomerate in the Wanganui River section. Applying the same procedure to the LO of *C. molestus* gives ages of 2.84 Ma in the Wanganui River section, 2.87 Ma in the Turakina River section, and 2.90 Ma in the Rangitikei River section.

Oxygen Isotope Stage Assignments:

The oxygen isotope timescale is derived from variation in the oxygen isotope composition of foraminifera derived from deep-sea sediments. By measuring the $^{18}O/^{16}O$ ratio of foraminiferal tests recovered from deep-sea cores relative to an isotopic standard, a rhythmically alternating pattern of successive ^{18}O enrichment and depletion linked to Milankovitch orbital parameters has been established, and calibrated with the Geomagnetic Polarity Timescale (Shackleton & Opdyke, 1973; Shackleton *et al.,* 1995). Notable studies contributing to the modern, detailed, oxygen isotope curves are derived from ODP (Ocean Drilling Project) sites in low-mid latitudes, with the most suitable being ODP site 846 from near the Galapagos Islands in the eastern Pacific (Shackleton *et al.,* 1995), ODP site 677 from easternmost equatorial Pacific (Shackleton *et al.,* 1990), DSDP site 607 from the mid-Atlantic (Ruddimann *et al.,* 1989; Raymo *et al.,* 1989), ODP 659 from the eastern Atlantic (Tiedemann, *et al.,* 1994), ODP site 758 from the northeast Indian Ocean (Chen *et al.,* 1995) and DSDP site 593 from the Tasman Sea (Head & Nelson, 1994). The oxygen isotope curve for each of these sites is illustrated in Figure 4.9, which demonstrates that known and consistent isotopic changes occurred during this interval. Traditionally, the isotopic fractionation is attributed partly to changes in the temperature of the waters in which the contemporary foraminifera grew, and partly to changes in the isotopic composition of the sea-waters driven by ice volume changes. These two factors probably operate a bit out of phase with each other (Chappell & Shackleton, 1986), but the magnitude of the total shift is usually attributed 1/3 to temperature and 2/3 to ocean volume resulting in sea-level change.

The variations in the $^{18}O/^{16}O$ ratio, which comprises the oxygen isotope curve, have been subdivided into "stages", with the system used by Shackleton *et al.* (1995) continued here. Note that the term "oxygen isotope stage" is abbreviated to "OIS".

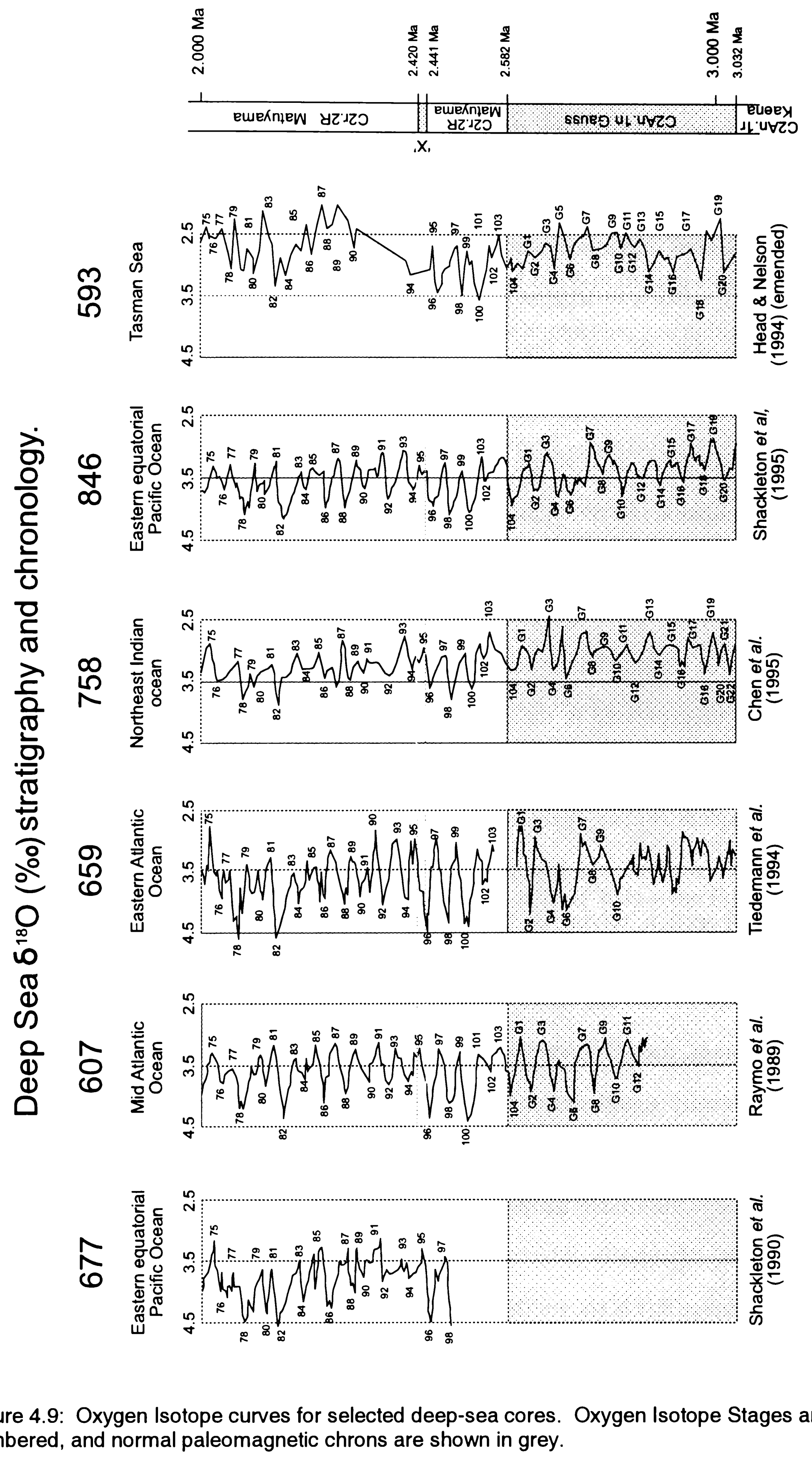

Figure 4.9: Oxygen Isotope curves for selected deep-sea cores. Oxygen Isotope Stages are numbered, and normal paleomagnetic chrons are shown in grey.

Previous studies attempting to match late Pliocene Wanganui Basin strata with the Oxygen Isotope timescale have been conducted by Naish *et al.*, (1996), Kamp *et al.*, (1998) and Kamp & McIntyre (1998), based on the magnetostratigraphy available at the time. These studies relied on the paleomagnetic data from Wilson (1993) and Naish *et al.* (1996) for the Rangitikei River section, where a magnetic reversal near the top of the Mangaweka Mudstone was correlated with the Gauss / Matuyama boundary. This study has confirmed the location of this transition 40 m below the top of the Mangaweka Mudstone. The G/M boundary lies within oxygen isotope stage 104 (Raymo *et al.*, 1989; Shackleton *et al.*, 1995)

Naish *et al.* (1996) interpreted the Mangarere Sandstone, which comprises 220 m of sandstone and siltstone, as a single 41 k.y. sequence. This implied an incredibly high sediment accumulation rate of 5.4 m/k.y. compared with a basin average of 0.5 to 1.0 m/k.y. The location of the G/M transition provides a key link between the section and the Oxygen Isotope timescale, as OIS Stage 104 is associated with the Gauss / Matuyama reversal. Naish *et al.* (1996) considered the sea-level rise associated with Stage 102 to 103 to be too insignificant to be expressed in the rocks, and thus correlated the base of the Mangarere Sandstone with Stage 100, and the Hautawa Shellbed with Stage 98. This model was used by many subsequent studies, including Kamp *et al.* (1998) for mid-Pliocene strata in the Rangitikei River section, and Kamp & McIntyre (1998) for late Pliocene strata in the Wanganui River section, relying on the assumption that the base of the Hautawa Shellbed (and thus the Mangapanian / Nukumaruan Stage boundary) was associated with OIS 98.

In the present study, the Mangarere Sandstone is interpreted as a slope channel, and not a cyclostratigraphically significant unit. This alternative interpretation does not invalidate the correlation of the base of the Mangarere Sandstone with OIS 100, but means that the Rangitikei River is unsuitable for precise determination of the age of the Mangapanian / Nukumaruan Stage boundary, which must be interpreted in the context of data from other sections. In chapter 8 it is shown that the Mangarere Sandstone contains multiple cycles, which are fully expressed in sections further to the east. The Hautawa Shellbed therefore must be younger than OIS 98.

Turakina River section:

The position of the Gauss / Matuyama paleomagnetic transition within the Mangaweka Mudstone some 100 m stratigraphically below the Okiwa Subgroup permits a correlation to be made with OIS 104, but cyclothems are not expressed lithologically at this level in the Turakina section. However, the occurrence of the "X" event allows the ages for the top and the bottom of this cryptochron to be transferred to the cyclothemic succession, and hence the isotope stages to be assigned to the sequences. Using the timescales of Cande & Kent (1992; 1995), the "X" event occurred between 2.441 and 2.420 Ma, which corresponds to the interglacial OIS 95, using the oxygen isotope timescale of Shackleton *et al.* (1995). Thus, the base of the shellbed above the "X" event (Te Rama Shellbed) can be correlated with OIS 94 (2.41 Ma), and the base of the shellbed stratigraphically below the cryptochron (Tirotiro Shellbed) can be correlated with OIS 96 (2.45 Ma). Assuming 41 k.y. cyclicity for the Mangapanian sequences above the Te Rama Shellbed, the bases of the Parihauhau and School Shellbeds can be correlated with OIS 92 (2.37 Ma) and OIS 90 (2.32 Ma) respectively. Thus, the base of the Hautawa Shellbed can be correlated with OIS 88, giving an age of 2.28 Ma for the Mangapanian / Nukumaruan Stage boundary.

Wanganui River section:

The location of the Gauss / Matuyama transition about 15 m below the Pitangi Formation permits isotope stage matching between cyclothems and oxygen isotope stages for the late Mangapanian strata in this section. The correlation between the base of the Otere Shellbed and OIS 102 is based on the shellbed being the first cyclothem following the Gauss / Matuyama boundary, which is associated with OIS 104, as explained above. Assuming a one-to-one match between cyclothems and oxygen isotope stages, this results in the following correlations: Otere Shellbed, OIS 102 (2.55 Ma); Wilkes Shellbed, OIS 100 (2.52 Ma); Mangamahu Shellbed, OIS 98 (2.48 Ma); Tirotiro Shellbed, OIS 96 (2.45 Ma); Te Rama Shellbed, OIS 94 (2.41 Ma); Parihauhau Shellbed, OIS 92 (2.37 Ma); School Shellbed, OIS 90 (2.32 Ma) and Hautawa Shellbed, OIS 88 (2.28 Ma). The match between the stratigraphy and the oxygen isotope curve for ODP Site 846 for this interval is illustrated in Figure 4.10.

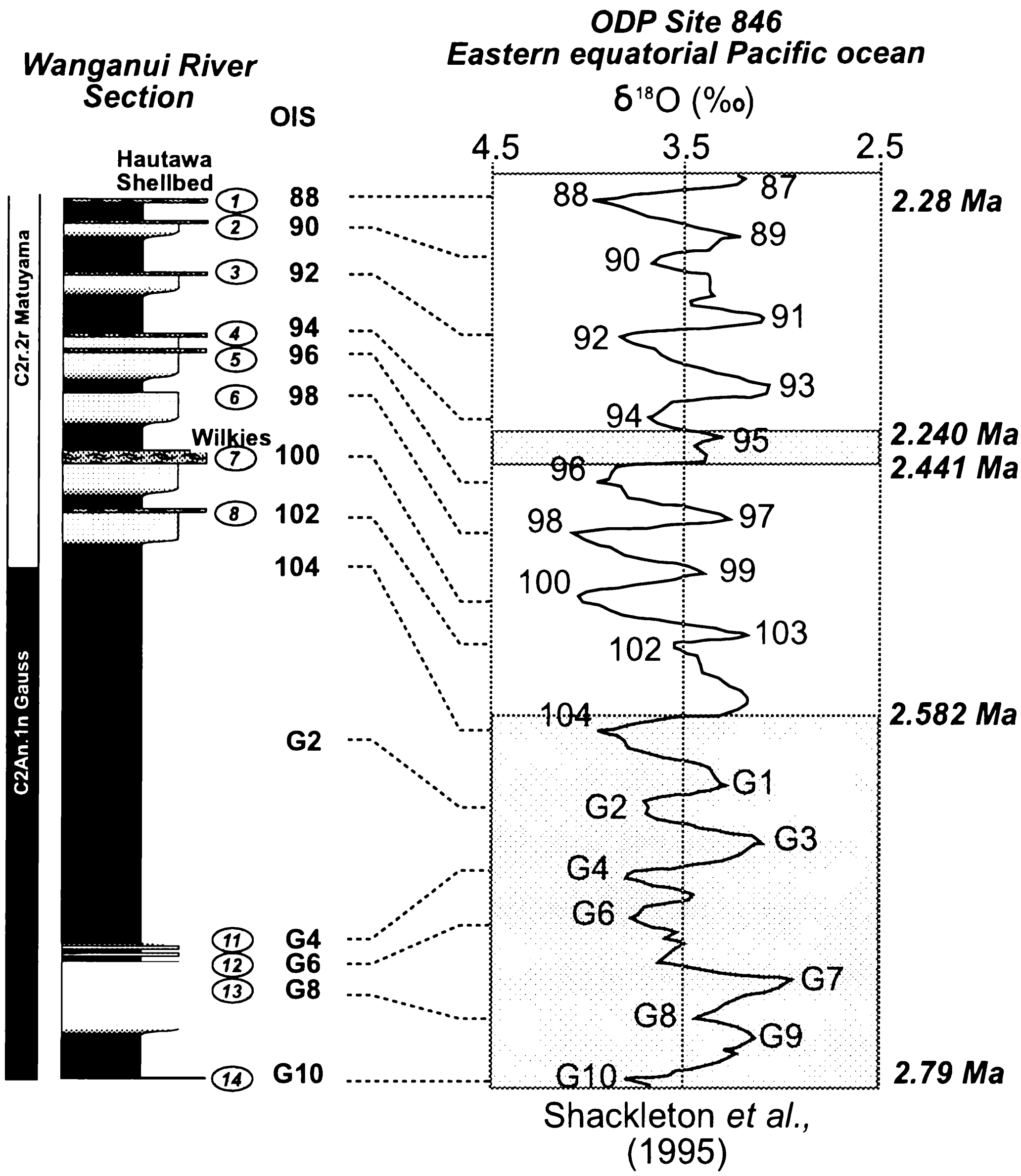

Figure 4.10: Correlation of Mangapanian Stage strata with Oxygen Isotope Curve for ODP site 846. Stratigraphy is from Wanganui River Section.

This interpretation supercedes that of McIntyre (1997), McIntyre & Kamp (1998) and Kamp & McIntyre (1998). The "X" event was not located in this section, but is predicted to lie in siltstone between the Tirotiro and Te Rama Shellbeds (OIS 94 and OIS 96), based on its occurrence in adjacent sections. While the ^{18}O shift of OIS 102 is of much smaller amplitude than other stages of similar age on most oxygen isotope curves (e.g. Raymo *et al.*, 1989; Shackleton *et al.*, 1995), it is used here because despite its smaller amplitude, it is nonetheless a valid 41 k.y. cycle on the ^{18}O timescale and therefore must be included. Failing to acknowledge OIS 102 as a ^{18}O shift sufficient to result in the formation of a cyclothem would necessitate including it within a cyclothem of c. 82 k.y. duration, which would be expected to have twice the thickness of other cyclothems within the succession. Since the Paparangi and Okiwa Subgroup cyclothems above the Gauss / Matuyama transition are of remarkably uniform thickness (c. 40 m), the inclusion of OIS 102 within a single cyclothem would require the occurrence of a cyclothem of between 55 and 80 m in thickness, an expectation which is not met in the cyclostratigraphy of this section. Figure 4.11 is a graph illustrating the mean thicknesses of complete (not erosionally truncated) Mangapanian cyclothems within the Okiwa and Paparangi Subgroups in some sections. The greatest mean thickness (~ 39 m) of cyclothems is in the Kauarapaoa valley section, and the general concordance of thickness of cyclothems within the basin between 30 – 40 m means that a cyclothem of 55 and 80 m thickness would be well outside the normal range. In sections to the west of this locality, the Otere Shellbed is underlain by several cyclothems. In particular, the Gully Shellbed correlates with oxygen isotope stage 104 (Figure 4.10). Correlation of each of the alternating sandstones and siltstones within the Pitangi Formation at Wairangi with the oxygen isotope stages indicates that the Mangapani Shell Conglomerate is associated with the inferred sea-level rise between Stage G10 (glacial) at 2.79 Ma and G9 (interglacial) at 2.81 Ma. Thus, the base of the Mangapani Shell Conglomerate (and hence the Waipipian / Mangapanian Stage boundary) can be dated at 2.79 Ma.

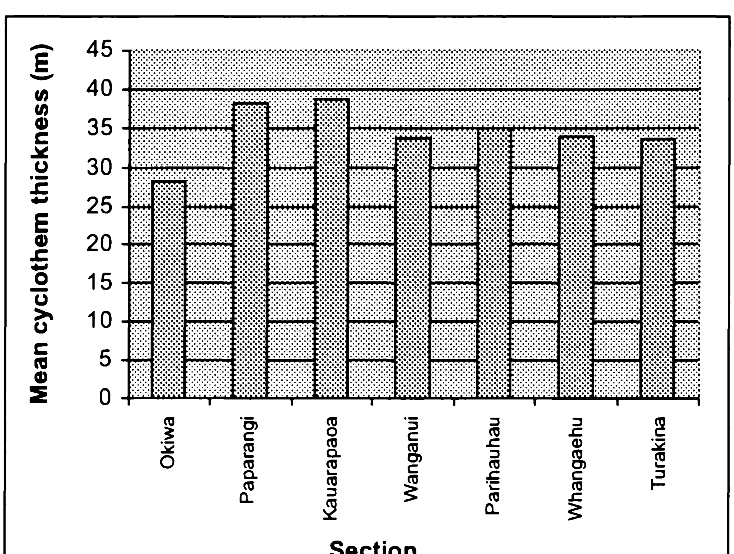

Figure 4.11: Mean thickness of complete cyclothems in Okiwa and Paparangi Subgroups for some sections.

Whangaehu River Section:

The magnetostratigraphic data for the Whangaehu River Section is limited to just four sample localities, but is consistent with the data from adjacent sections. The occurrence of a normal polarity interval below the Te Rama Shellbed (shellbed 4) indicates the top of the "X" normal event, and thus allows a correlation to be made between the strata and the oxygen isotope curve. Using the cyclothem to OIS correlation, this gives a match between the Hautawa Shellbed and OIS 88, (2.28 Ma), the same result as for adjacent sections for which magnetostratigraphic data exists.

Kauarapaoa and Paparangi Sections:

Using the "X" normal event as a match to the Oxygen Isotope curve, an identical Oxygen Isotope stratigraphy can be determined for these sections as found in the localities described above. The occurrence of the "X" event between the Te Rama and Mangamahu Shellbeds in both these sections permits a match to be made between these shellbeds and OIS 94 and OIS 96. Simple counting of oxygen isotope stages to overlying cyclothems is not possible in this section because the School Shellbed in the Paparangi section has been eroded in an unconformity beneath the Kuranui Limestone.

Summary of Integrated chronology.

By the integration of paleomagnetic datums, sequence ocurrence and oxygen isotope stages, this study dates the Mangapanian Stage as occurring between 2.79 and 2.28 Ma, an interval of 0.51 m.y. A table summarising the ages assigned to the various datums within the field area is presented below:

Table 4.1: Oxygen Isotope assignments and absolute ages of bioevents and paleomagnetic chrons associated with the Mangapanian Stage, Wanganui Basin.

Datum	Oxygen Isotope Stage	Age (Ma).
End Mangapanian Stage	**88**	**2.28 Ma**
FO *Rotalia wanganuiensis*	**88**	**2.28 Ma**
FO *Globorotalia crassula*	**88** (based on single specimen)	**2.28 Ma**
FO *Zygochlamys delicatula*	**88**	**2.28 Ma**
FO *Phialopecten triphooki*	**88**	**2.28 Ma**
FO *Mesopeplum convexum*	**88**	**2.28 Ma**
LO *Crassostrea ingens*	**88**	**2.28 Ma**
LO *Phialopecten thomsoni*	**90**	**2.32 Ma**
LO *Alcithoe gatesi*	**90**	**2.32 Ma**
LO *Alcithoe brevis*	**90**	**2.32 Ma**
Top "X" event cryptochron	**94**	**2.42 Ma**
Base "X" event cryptochron	**96**	**2.441 Ma**
Gauss / Matuyama reversal	**104**	**2.582 Ma**
FO *Phialopecten thomsoni*	**G10**	**2.79 Ma**
FO *Tawera subsulcata*	**G10**	**2.79 Ma**
FO *Pelicaria* n.sp. aff. *zelandica*	**G10**	**2.79 Ma**
FO *Penion sulcatus*	**G10**	**2.79 Ma**
Start Mangapanian Stage	**G10**	**2.79 Ma**
LO *Cibicides molestus*	**G11**	**2.81 Ma**
LO *Saracenaria italica*	**G11**	**2.81 Ma**
LO *Semicassis fibrata*	**G11**	**2.81 Ma**
LO *Alcithoe* cf. *whakinoensis*	**G11**	**2.81 Ma**
Top Kaena subchron	**G21**	**3.032 Ma**
Base Kaena subchron	**KM1**	**3.116 Ma**
FO dex. *Globorotalia crassaformis*	**KM2**	**3.13 Ma**

Figure 4.13: (facing page) Molluscs whose first occurrences mark the base of the Mangapanian Stage. a) *Penion sulcatus.* b) *Pelicaria* n.sp. aff. *zelandiae.* c) *Tawera subsulcata.* d) *Phialopecten thomsoni.* (All actual size).

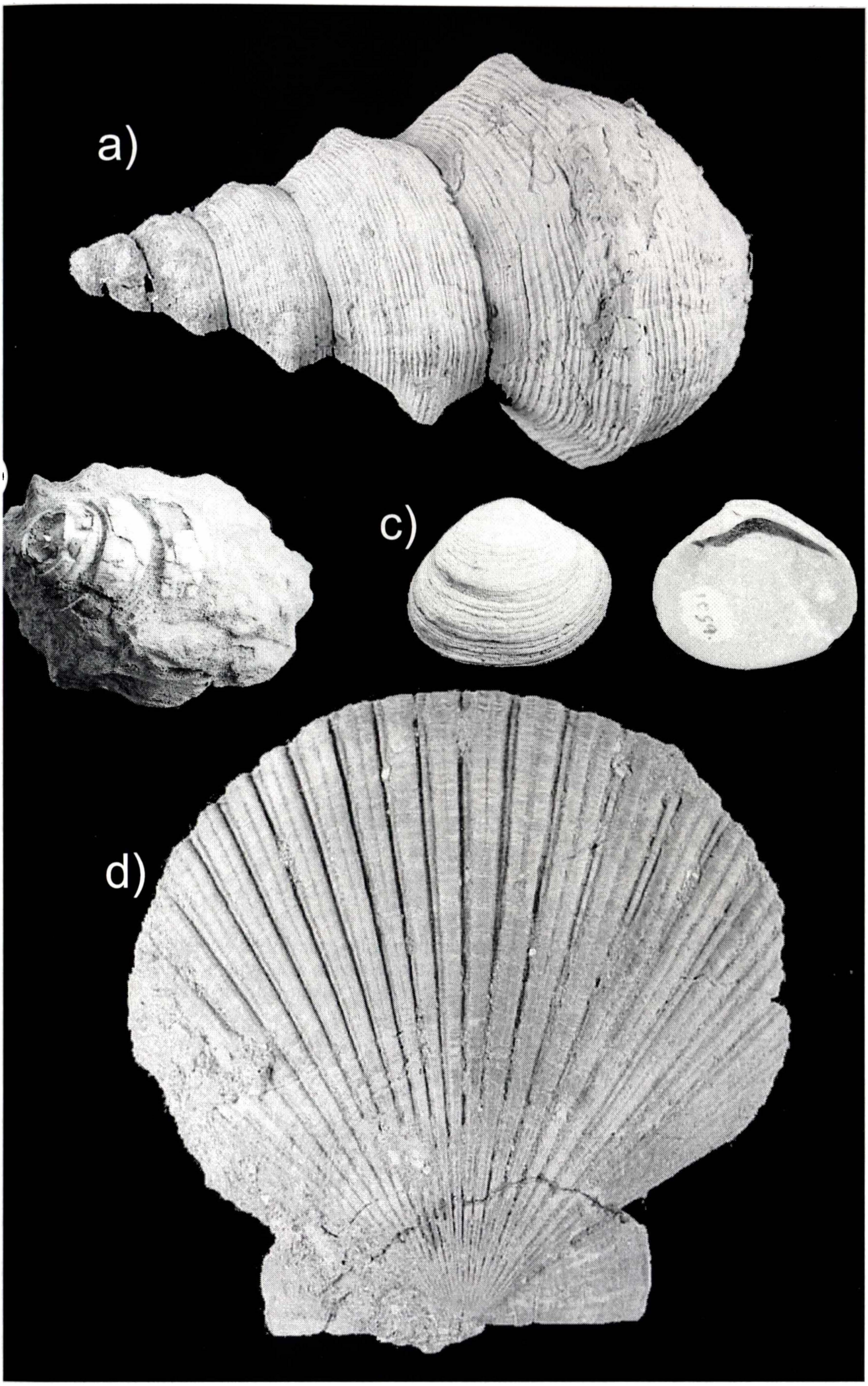
a)
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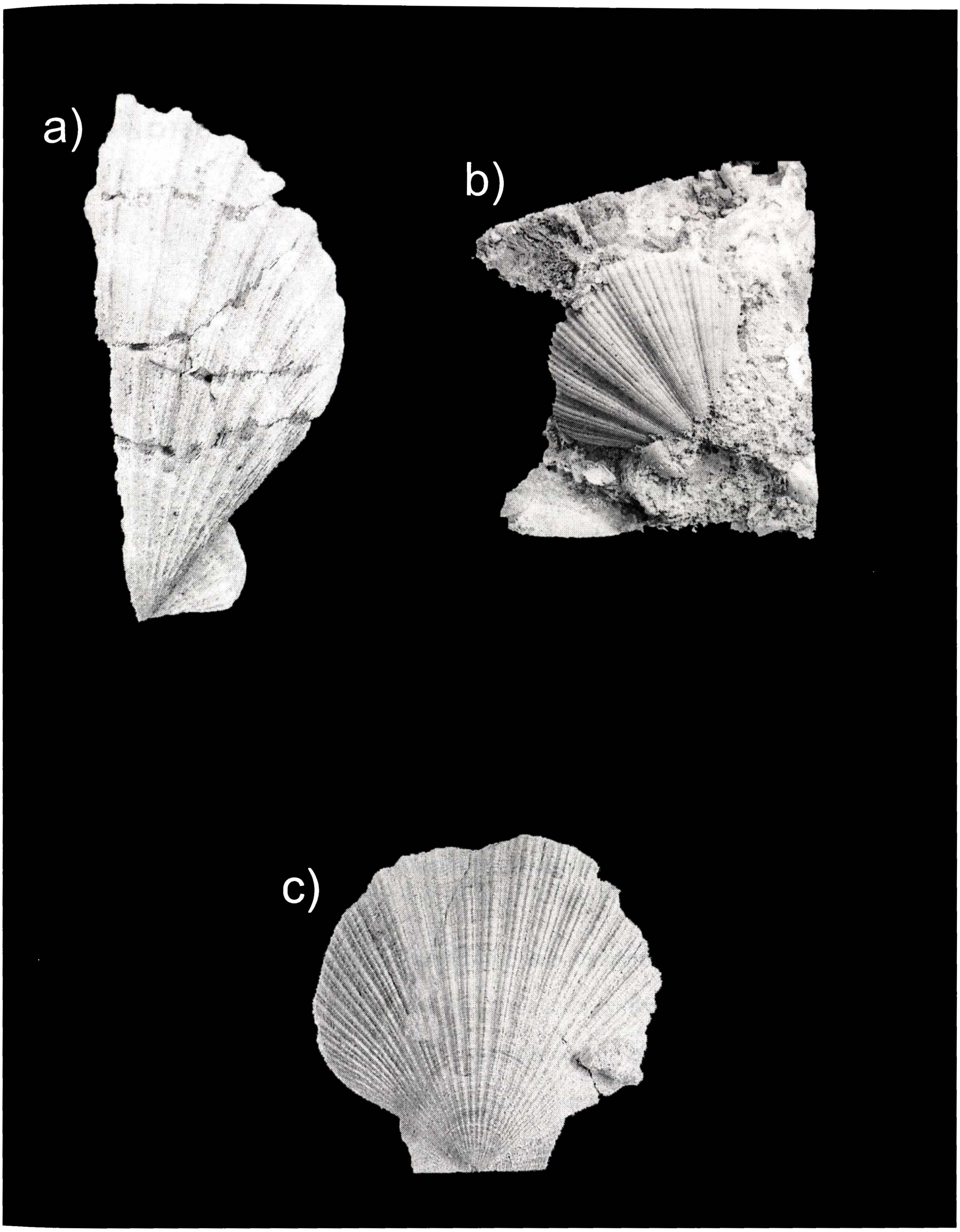
Figure 4.13: (facing page) *Crassostrea ingens,* the giant oyster whose extinction marks the end of the Mangapanian Stage. A brief interval of dual occurrence of *C. ingens* and *Phialopecten triphooki* (and/or *Zygochlamys delicatula*) is a useful early Nukumaruan indicator.

Figure 4.14: (facing page) The Mangapanian-restricted scallop *Phialopecten thomsoni.* (actual size).

Figure 4.15: (facing page) Scallops whose first occurrences mark the base of the Nukumaruan Stage. a) *Phialopecten triphooki*; b) *Mesopeplum convexum*; c) *Zygochlamys delicatula*. (all actual size).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CHAPTER FIVE:

THE MANGAPANI SHELL CONGLOMERATE: A SHORELINE TO UPPER BATHYAL PERSPECTIVE OF A TRANSGRESSIVE DEPOSIT.

Introduction.

History:

The occurrence of shellbeds in the sedimentary succession of Wanganui Basin was first noted by Mantell (1848). Subsequent studies focused on the beds exposed well in coastal cliffs between Wanganui and Hawera (Hector, 1870; Park, 1887; Park, 1910; Marshall & Murdoch, 1920). Exposure of the Wanganui Series is almost continuous along this stretch of coastline, with the exception of a 5 km-wide interval at the mouth of the Waitotara River where the sediments are covered by Holocene sand dunes. This obscured interval includes strata between the upper Waipipian and lower Nukumaruan Stages. The only outcrop occurs on the true left bank of the Waitotara River about 1 km inland from the coast. This locality is Wilkies Bluff (Park, 1887) and contains two shellbeds, 1.5 and 3 metres thick respectively, separated by 5 metres of laminated sandstone.

The first published investigation of Mangapanian beds inland from the coastal section was made by Laws (1940), who published a list of molluscs collected from what became the type section of the Mangapani Shell Conglomerate in Mangapunipuni valley. By comparing the fauna of the "Beds at Mangapani" with other collections from Nukumaru Beach (presumably numerous shellbeds), Wilkies Bluff, Waipipi Beach (Waipipi Shellbeds) and shellbeds near Hawera (Waihi Beach), Laws correctly positioned the Mangapani Shellbed in the interval separating the shellbeds at Waipipi beach and Wilkies Bluff. Using the New Zealand Stage system at the time, he included the Mangapani Shell Conglomerate in the Nukumaruan Stage (subsequently emended). While this study was primarily paleontological, Laws (1940) provided a brief description of the shellbed at Mangapani, noting that the unit consisted of two parts, with a fossiliferous "loose brown micaceous quartz sand of shallow water character underlying six to eight feet of flaggy limestone which contains large pectens here and there near its base".

The first study that linked the coastal section to ones inland was Fleming (1953), who mapped the area between the coastal section (Wanganui River mouth to Waipipi Beach) and the Turakina River valley. In this work, he evaluated the stratigraphy and molluscan paleontology of the strata and established several biostratigraphic stages on which most of the current New Zealand Plio-Pleistocene timescale is based. The strata below the marine terrace deposits were subdivided into three main stages: Waitotaran, Nukumaruan and Castlecliffian Stages. Each of these stages had two associated substages. The Waitotaran Stage included the Waipipian substage and the Mangapanian substage. The shellbed at Mangapani, which he named the "Mangapani Shell Conglomerate", marked the base of the Mangapanian Substage. The Waipipian and Mangapanian Substages have been identified outside Wanganui Basin, which has resulted in their elevation to full stage status (Beu, 1969). This has made the Waitotaran Stage redundant. However, the substages within the Nukumaruan and Castlecliffian have proved less useful, and have been generally abandoned (Beu, 1969; 1970; 1995).

Fleming (1953) designated the basal contact of the Mangapani Shell Conglomerate as the boundary between the Waipipian and Mangapanian Stages, with the Mangapanian / Nukumaruan boundary coincident with the base of the Hautawa Shellbed. Fleming (1953) mapped the Mangapani Shell Conglomerate about 12 kilometres southwestwards from the type section to just north of Waitotara township.

Since Fleming's bulletin was published, subsequent reference was made by Arnold (1957), who described the stratigraphy of the upper Waitotara valley and constructed a column up to and including the Mangapani Shell Conglomerate. He also described a locality of the Mangapani Shell Conglomerate on the eastern part of Waipipi beach. Attempts to find this locality as part of this study have proved unsuccessful, as it is now covered by sand dunes, and therefore cannot be confirmed.

Collen (1972) was unable to identify any foraminiferal bioevents across the Mangapani Shell Conglomerate and therefore did not distinguish the Waipipian and Mangapanian Stages at the type section. This was probably because the shallow-water nature of the strata in the lower Waitotara valley section has precluded the accumulation and preservation of planktic foraminifera, and also the high level of weathering in parts of the section indicates that dissolution of carbonate material has taken place. Beu (1978) re-examined *Phialopecten* specimens from Fleming's (1953) collection from the Mangapani Shell Conglomerate in a taxonomic and biostratigraphic study of *Phialopecten* and *Mesopeplum.* He re-visited the type section to collect further *Phialopecten* specimens for his 1995 publication "Pliocene Limestones and their Scallops" (Beu, pers. comm., August, 1998).

Purpose of Study:

The Mangapani Shell Conglomerate is an important horizon in the Wanganui Series because: a) it is one of the more prominent units in the western part of the basin, (especially in sections in and near the Waitotara River valley), and b) it contains several molluscan biostratigraphic datums. These two features assist in correlation of the unit between sections. This study shows that the Mangapani Shell Conglomerate crops out in the Wairangi stream and Wanganui River valley sections, and possibly also in the Mangawhero valley, all east of the type locality. In each of the five main sections described in this study, the Mangapani Shell Conglomerate has a different facies expression, reflecting differences in its depositional environment. The faunal lists of Laws (1940), Fleming (1953) and Beu (1995) have been used to supplement the new collections made as part of this study.

Stratigraphic Context:

The Mangapani Shell Conglomerate occurs between Waitotara township in the west and the Wanganui River valley to the east. Further east it passes into the Mangaweka Mudstone losing expression as a shellbed (Figure 5.1). In Wanganui and Mangawhero valleys the shellbed occurs at the base of the Atene Formation. This formation is the uppermost part of a wedge of shelfal deposits extending eastwards from the Patea-Tongaporutu High into Wanganui Basin. The Atene Formation is well exposed about 2-3 km south of Otoko Pa in the Mangawhero River valley, but the Mangapani Shell Conglomerate has not been identified there. However, Mangapanian fossils occur within part of the sandstone.

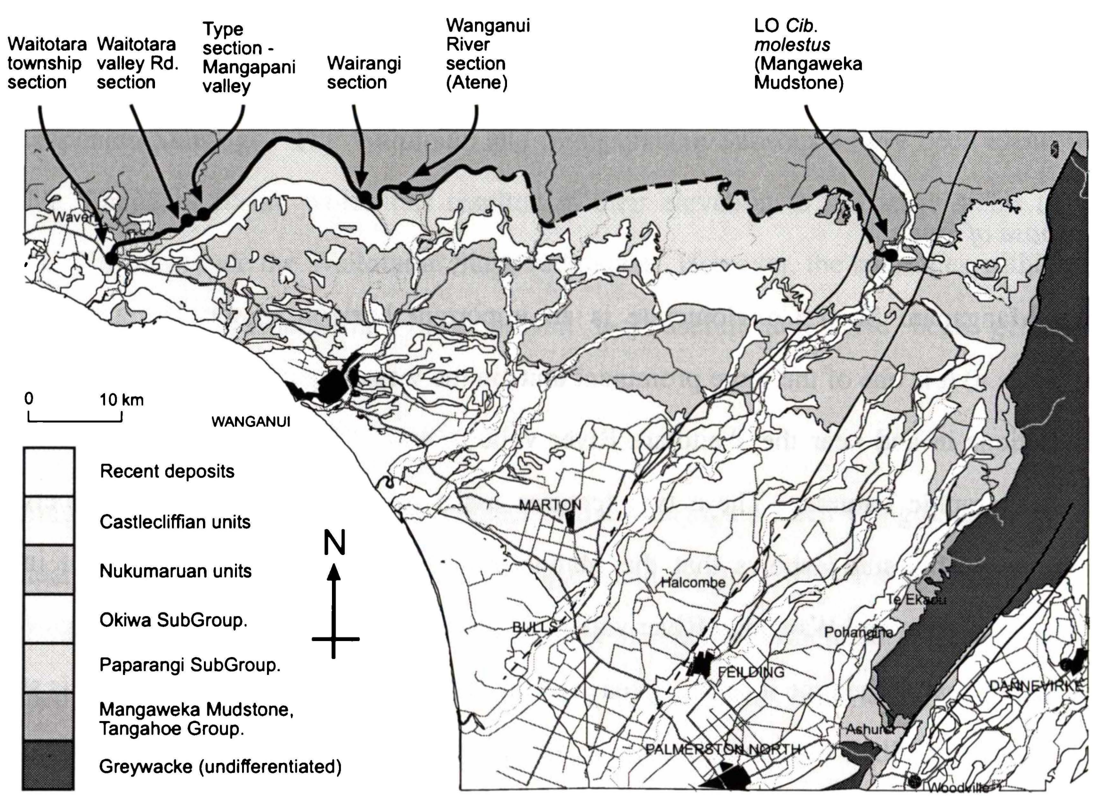


Figure 5.1: Map of Wanganui Basin showing outcrop distribution of major stratigraphic units, with thick line showing outcrop of Mangapani Shell Conglomerate rocksacross the basin.

Correlation of the shellbed between the Waitotara valley and the Wanganui valley is based on several factors:

In Waitotara valley, the Mangapani Shell Conglomerate is the only thickly developed shellbed within several hundred metres of rocks. Consequently, any shellbed at a comparable stratigraphic level in adjacent sections is probably this unit. The Mangapani Shell Conglomerate is thickest in sections between the Waitotara valley and Waitotara township, which allowed Fleming (1953) to map it more-or-less continuously in this area.

The Mangapani Shell Conglomerate is the only Mangapanian shellbed containing a significant proportion of quartz and greywacke pebbles and/or cobbles. This is a feature of the unit in all of its sections, with the pebble size and amount greatest near Waitotara township, and the least quantities occurring in Wanganui valley. The Te Rama Shellbed (late Mangapanian) also contains pebbles in places, but in much lesser amounts compared with the Mangapani Shell Conglomerate, and is usually between 350-800 m stratigraphically above it, making differentiation between the two shellbeds simple.

Several molluscan bioevents associated with the Mangapani Shell Conglomerate assist with its correlation between sections. These also provide chronological data for the sections in which they occur. In the western sections (Waitotara River valley and Mangapani valley) the FO of the Mangapanian-restricted scallop *Phialopecten thomsoni* and the bivalve *Tawera subsulcata* occur throughout and within the basal part of the unit. Specimens of the Waipipian scallop *Mesopeplum crawfordi* have been found at Kowhata, 500 m stratigraphically below the Mangapani Shell Conglomerate in the Waitotara valley.

In the Wairangi Stream section, the only biostratigraphic datum found is the FO of the unnamed, Mangapanian-restricted gastropod *Pelicaria* n.sp. aff. *zelandiae,* which has been recovered from siltstone facies immediately above the shellbed. In the Wanganui River section, the Mangapani Shell Conglomerate also contains several bioevents, with the FO of the gastropods *Pelicaria* n.sp. aff. *zelandiae* and *Penion sulcatus* in the upper part of the shellbed. In addition, the LO of the benthic foraminifer *Cibicides molestus* occurs immediately above the Te Tuhi Shellbed Member (110 m stratigraphically below the Mangapani Shell Conglomerate), and the FO of dextrally coiled *Globorotalia (Truncorotalia) crassaformis* occurs somewhere between 600 and 750 m stratigraphically below the Mangapani Shell Conglomerate, within the Koroniti Sandstone (Hayton, 1998).

Age of the Mangapanian / Waipipian Stage boundary:

The Mangapani Shell Conglomerate was first considered to have a Pliocene age by Fleming (1953), and defined as the boundary between the Waipipian and Mangapanian stages. The current estimate for this age is 3.03 Ma (Beu, 2001).

Age estimates of the Mangapani Shell Conglomerate in this study have been obtained through integrating magnetostratigrapy, sediment accumulation rates and the matching of cyclothems with oxygen isotope stages (Chapter 4). The Gauss chron (C2An) corresponds with the Waipipian Stage, through to the middle of the Mangapanian Stage. The paleomagnetic transition closest to the Mangapani Shell Conglomerate is the top of the Kaena subchron (C2An.1r), occurring at 3.032 Ma (Lourens *et al.,* 1996). In the Wanganui River section, this transition at the top of the subchron is located between 350 and 450 m below the Mangapani Shell Conglomerate. Above the shellbed, the top of the Gauss normal chron (Gauss / Matuyama reversal - C2An.1n / C2r.2r) at 2.582 Ma (Lourens *et al.,* 1996) occurs near the top of the Mangaweka Mudstone, some 500 m upsection. Assuming linear sediment accumulation rates, simple interpolation between these two points gives an age of 2.79 Ma for the Mangapani Shell Conglomerate (Figure 5.2).

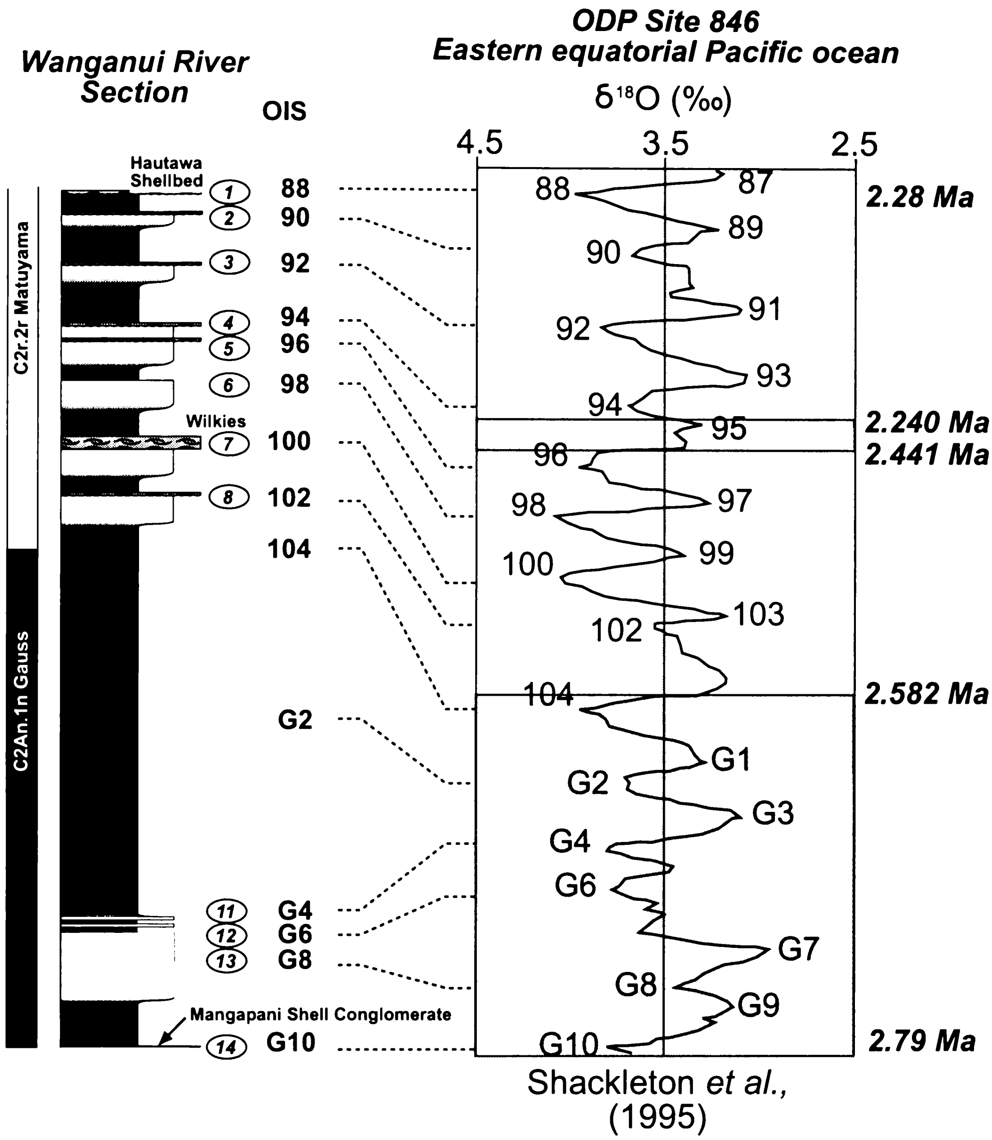


Figure 5.2: Correlation of Mangapanian Stage strata with Oxygen Isotope Curve for ODP site 846. Stratigraphy is from Wanganui River Section, and shows the correlation between the Mangapani Shell Conglomerate (at base of column) with OIS G10.

Another approach to establishing the age of the Mangapani Shell Conglomerate is by matching cyclothems to the oxygen isotope timescale. In the Wanganui valley, the Gauss / Matuyama paleomagnetic reversal (2.582 Ma) occurs just below the Otere Shellbed Member. In sections to the west of this locality, the Otere Shellbed is underlain by several cyclothems. In particular, the Gully Shellbed correlates with Oxygen Isotope Stage 104 (Figure 5.2). Correlation of each of the alternating sandstone and siltstone beds within the

Pitangi Formation at Wairangi with the oxygen isotope stages indicates that the Mangapani Shell Conglomerate is associated with the inferred sea-level rise between Stage G10 (glacial) and G9 (interglacial). This gives an age for it of 2.81-2.79 Ma, using the isotope timescale of Shackleton *et al.,* (1995). The close match of ages from these two approaches indicates an age estimate ranging between 2.80 and 2.81 Ma for the base of the Mangapani Shell Conglomerate and hence the Waipipian / Mangapanian boundary. The age of the LO of the benthic foraminifer *Cibicides molestus* in the Rangitikei, Turakina and Wanganui River valleys based on assumed linear sedimentation between the top of the Kaena subchron (3.032 Ma) and Gauss Chron (2.582 Ma) gives ages of 2.90, 2.87 and 2.84 Ma respectively, slighty older than for the Mangapani Shell Conglomerate. However, this is not unexpected, given the ~ 90 m gap between the LO of *C. molestus* and the Mangapani Shell Conglomerate in this section. It is quite possible that perhaps the molluscan bioevents seen in the Mangapani Shell Conglomerate could have occurred less than one cycle before deposition of the shellbed, but are not evident in the stratigraphy because of unsuitable conditions until deposition of the shellbed.

Shellbed stratigraphy and sedimentology.

Across Wanganui Basin, there are noticeable variations in the thickness, facies, faunal abundance, composition and bounding surfaces of the Mangapani Shell Conglomerate. While the Mangapani Shell Conglomerate is only found in the western parts of the basin, it can be correlated into the Mangaweka Mudstone, which is a deeper-water equivalent of the Waverley, Atene and Pitangi Formations. East of Mangawhero River valley, the LO of *Cibicides molestus* has been located in the Whangaehu River valley section (see chapter 4), the Turakina River valley section (MacGuire, 1989) and in the Rangitikei River valley section (Journeaux *et al.,* 1996). The following decriptions of the Mangapani Shell Conglomerate, Soulsby Siltstone and Atene Sandstone Members includes facies codes, which are tabulated in Table 5.1.

Table 5.1: Facies groups and lithofacies codes used for description of Mangapani Shell Conglomerate and associated lithologies, Wanganui Basin.

Groups	Lithofacies code	Description	Typical example	Depositional environment
Siltstone Group	Z_1	Barren to sparsely fossiliferous, massive bioturbated siltstone	Soulsby Zst, Wairangi	Mid-shelf
	Z_2	Barren to sparsely fossiliferous, massive, bioturbated fine sandy siltstone	Soulsby Zst, Waitotara Rd.	Inner–mid shelf
	Z_3	Barren to sparsely fossiliferous alternating centimeter to decimetre siltstone and fine sandy siltstone beds (silt dominant)	Zst beneath Mangapani S C, Wairangi	Inner-shelf, possibly estuarine
Sandstone Group	S_1	Barren to sparsely fossiliferous, massive, bioturbated, silty fine sandstone	Sst beneath Mangapani S C, Atene	Inner-shelf
	S_2	Barren to moderately fossiliferous, bioturbated, massive fine micaceous sandstone	Atene Sst, Waitotara Rd.	Shoreface
Shellbed Group	Cz_2	Closely packed shells (*Ostrea, Purpurocardia, Crepidula, Crassostrea,* Brachiopods) within bioturbated fine sandy siltstone. Shell dominated	Top Mangapani Shell Conglom., Wairangi	Outermost Inner-shelf – mid-shelf
	Cz_3	Dispersed, matrix supported near–in *situ* shells (*Alcithoe, Antalis, Pelicaria, Pratulum*) within bioturbated siltstone	Base Soulsby Zst, Atene	Mid-shelf
	Cs_1	Closely packed shells (typically bivalves – *Eumarcia, Dosinia, Gari, Divaricella, Pteromyrtea*) within bioturbated silty sandstone and sandstone	Base Mangapani Shell Conglom., Wairangi	Inner-shelf
Limestone Group	Cl_1	Cross–bedded, flaggy, pebbly, shell hash limestone with *Phialopecten, Ostrea, Atrina* and *Crepidula* common.	Top Mangapani Shell Conglom., Waitotara Rd.	Inner-shelf

Wanganui River valley section: (Figure 5.3a)

In the Wanganui River valley, the Mangapani Shell Conglomerate crops out in a road cutting about 2.5 kms north of Atene Pa (S21/924633). In this section the shellbed is very weakly developed, consisting of a few molluscs occurring in the fossiliferous basal 2 m of a 40 m-thick blue-grey siltstone bed (facies Z_1), which conformably overlies a similarly coloured sandstone bed (S_1) containing rare *Divaricella* in the upper 30 cm. Apart from a subtle break in sedimentation 1 m below the top of the sandstone, no bedding structures are obvious, and the contact between the sandstone and siltstone has little or no relief. Small greywacke pebbles up to 5 mm in diameter are dispersed fairly evenly throughout the shellbed, about 50 cm apart (Hayton, 1998). In the upper part of the shellbed (Cz_3), small lenses and pockets of *Pratulum* occur, along with scattered specimens of *Tiostrea, Chlamys* and *Atrina.* The gastropods *Pelicaria* n.sp. aff. *zelandiae* and *Penion sulcatus* have been recovered from the upper part of the shellbed, confirming a Mangapanian age. Within the siltstone (Soulsby Siltstone) above the shellbed, there is a slight increase in grain size in the central part (facies Z_2), before becoming finer for the upper 15 m (Z_1). Above the siltstone, the Atene Sandstone crops out in the bluffs surrounding the abandoned oxbow at Atene Pa, the type section of the Atene Sandstone. Two prominent weakly lithified sandstone horizons, which are a distinctive feature of the upper part of the Atene Formation, are very obvious at this locality. The upper sandstone units of the Atene Formation total 70 m thick (facies S_3), with the total thickness of the formation being 110 m (modified from Hayton, 1998).

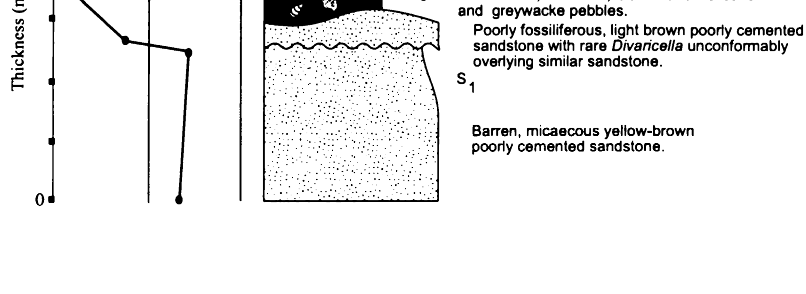


Figure 5.3a: Lithological detail of Mangapani Shell Conglomerate, Wanganui River valley, Atene.

Kauarapaoa Stream section: (Figure 5.3b)

The Mangapani Shell Conglomerate is very poorly exposed in the Kauarapaoa section, cropping out at the base of a waterfall in an unnamed tributary flowing into the Kauarapaoa Stream, at Wairangi Station (R21/846625). Here, the shellbed is 0.5 m thick, unconformably overlying flaser-bedded (1-2 cm) Waverley Formation sandstone (facies Z_4). The shellbed is significantly more strongly developed than in the Wanganui River valley section, with common *Divaricella* in the lower (facies Cg_2) and *Crassostrea* in the upper (Cz_2) parts. The greywacke and quartz pebbles in the shellbed at this location are commonly up to 13 mm in diameter (one specimen collected was 23 mm). Above the shellbed, a 38 m-thick siltstone bed is well exposed, and has been named the Soulsby Siltstone, this being its type section (new member, defined in Chapter 2). The three alternations between siltstone (all facies Z_2) and sandstone (S_{1-3}) in the Atene Formation are all present, with a combined thickness of 72 m. The gastropod *Pelicaria* n.sp. aff. *zelandiae* has been recovered from the Soulsby Siltstone, confirming its Mangapanian age. The top of the Atene Formation is marked by the double sandstone beds (S_3) characteristic of this unit in the Wanganui and Waitotara valleys, cropping out on the hillside above the Wairangi Station access road. The Atene Formation is also well exposed in a cutting on the Kauarapaoa Road (R21/873624) where large-scale, low-angle tabular cross beds occur (S_5). The general stratigraphy of the lower part of the Atene Formation in this section where the Mangapani Shell Conglomerate occurs is summarised in Figure 5.3b.

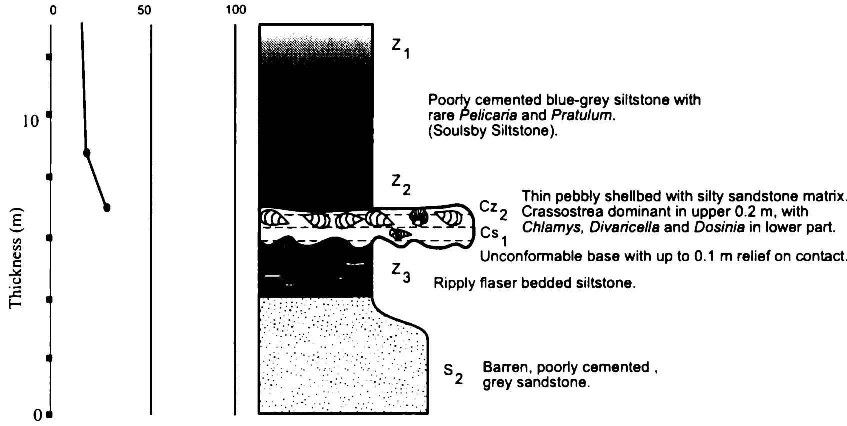


Figure5.3b: Lithological detail of Mangapani Shell Conglomerate, Wairangi Station, Kauarapaoa valley.

Mangapunipuni (Mangapani) valley, (Type section): (Figure 5.3c)

At the type section (R21/671613) the Mangapani Shell Conglomerate is substantially thicker and more fossiliferous than in the Wairangi and Wanganui valley sections, with a total thickness of 6 m. The unit itself has two distinct parts, which are in direct contact with each other. The lowermost part is a 0.6 m-thick, uncemented sandy and pebbly shellbed (Cg_2) scoured into yellow-brown micaceous sandstone of the Waverley Formation (S_3). There is wide faunal diversity, with common *Tucetona, Maoricardium, Eumarcia* and *Crepidula*. The upper part of the Mangapani Shell Conglomerate is a 5 m-thick, well cemented shell hash limestone with disarticulated valves of *Phialopecten thomsoni* concentrated near the base (CL_1). The contact between the lower shellbed and the upper limestone has relief of up to 0.2 m, but does not appear to be erosional, as the contact mimics the general bedding pattern of the lower shellbed part of the unit. Bryozoa and barnacles become more common near the top of the limestone, and rare *Atrina* and *Crassostrea* occurring throughout the limestone. While pebbles occur throughout the shellbed and limestone, the greatest abundance and size (commonly 22 mm in diameter, but specimens up to 50 mm have been found) occur in the lower (shellbed) part, with the clasts in the limestone being smaller and more dispersed. The Atene Formation siltstone and sandstone beds are very poorly exposed at this location. However, a few metres of the Soulsby Siltstone (Z_2) is exposed above the limestone. Fig 5.3c shows a graphic log of the Mangapani Shell Conglomerate at its type section.

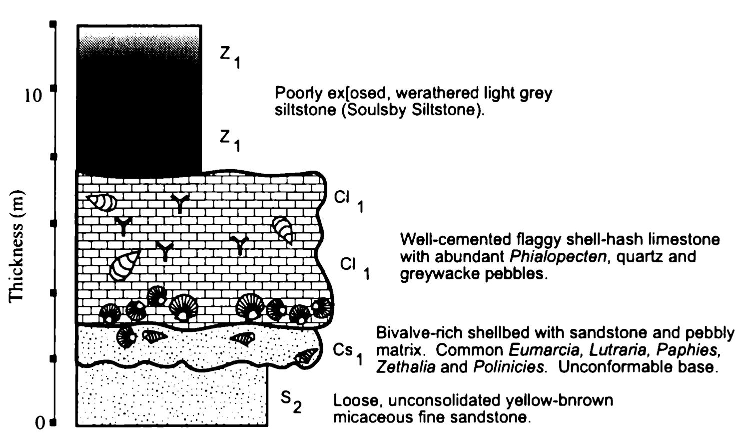


Figure 5.3c: Lithological detail of Mangapani Shell Conglomerate, Mangapunipuni valley (Type section).

Waitotara River valley section: (Figure 5.3d)

The Waitotara River and Mangapani valley sections are only about 1.6 km apart. At its exposure on the Waitotara valley road (R21/660604) the total thickness of the shellbed and the limestone members is 4.5 m, including a 1.4 m-thick sandstone bed separating the two units (Figure 3d). The lower (shellbed) part is 0.4 m thick, with a very similar facies to that of the lower shellbed at the type section (facies Cg_2). It is unconformable on the underlying Waverley Formation sandstone (S_3), with scoured troughs and burrows at its base. Bivalves dominate the lower part, with *Eumarcia, Gari, Lutraria, Spisula* and *Tawera* common to abundant. Gastropods include *Zethalia, Polinices* and *Maoricolpus,* with pebbles (30 mm in diameter) also abundant in the sandstone matrix. Between the shellbed and the limestone, the intervening 1.4 m-thick sandstone bed is strongly tabular-bedded, with ~ 10 cm thick beds of alternating texture, and finer grained flaser beds (1 mm thick) occurring throughout the unit (facies S_4). The upper limestone bed (2.5 m thick, facies CL_1) is well cemented, with pebbles and very large (over 150 mm wide) *Phialopecten thomsoni* specimens dominating the faunal assemblage, especially at the base of the unit. The contact between the bedded sandstone and the limestone appears to be semi-erosional, marked by a thin (< 10 cm thick) layer of pebbles of similar size to those found in the lower shellbed. Above the shellbed, the rest of the Atene Formation is dominated by sandstone (S_2), giving a total thickness of 73 m for the formation.

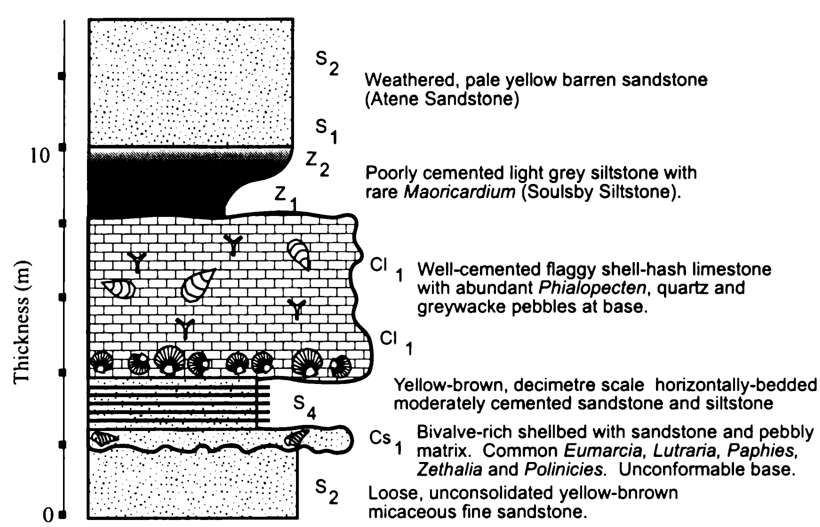


Figure 5.3d: Lithological detail of Mangapani Shell Conglomerate, Waitotara valley roadside.

Waitotara township (State Highway 3): (Figure 5.3e)

The westernmost section containing the Mangapani Shell Conglomerate is in an abandoned limestone quarry about 2 km north of Waitotara township on SH 3 (R22/570553). Here the shellbed is 10 m thick, with the 4 m-thick lower part consisting of a pebbly sandy shell hash limestone with decimetre scale, steeply (~30°) northwards-dipping foresets containing rare casts and fragments of *Phialopecten thomsoni, Perna, Tiostrea* and *Sigapatella.* In the upper part of the Mangapani Shell Conglomerate there are two beds, both 2 m thick, of alternating bi-directional, low-angle, herringbone crossbeds separated by a 2 m-thick horizontally bedded interval, which is more sandier than the more cross-bedded layers (Figure 5.3e). Above the limestone, the Atene Sandstone (5 m thick) directly overlies the Mangapani Shell Conglomerate. It contains rare barnacles and *Ostrea*, and is sharply overlain by a sandy siltstone bed, which is inferred to be a lateral equivalent of the Mangaweka Mudstone.

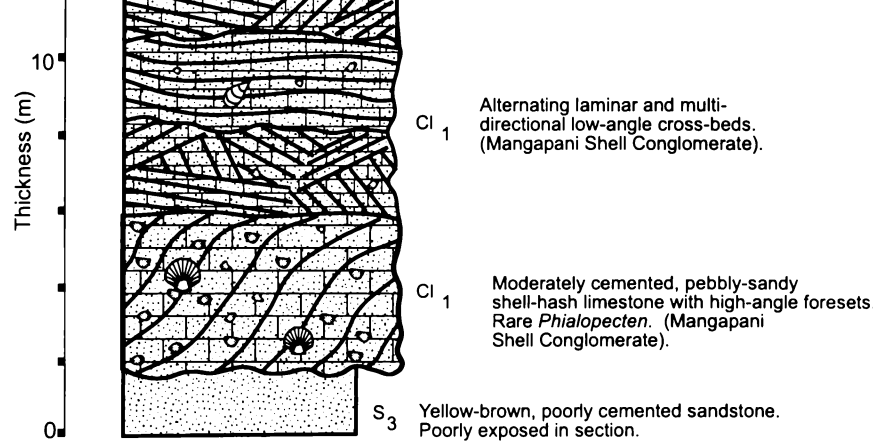


Figure 5.3e: Lithological detail of Mangapani Shell Conglomerate, Abandoned quarry near SH3, Waitotara.

Molluscan paleoecology and bathymetry.

Collections:

Compared with many of the other more rarely studied shellbeds in Wanganui Basin, the Mangapani Shell Conglomerate has been collected as part of several investigations. The earliest faunal list is from the type section (Laws, 1940). Fleming (1953) listed collections from five locations, comprising (from east-west) the type section, Waitotara valley Road, Puao Track, Moumahaki valley and the Waitotara SH3 Quarry section. Beu (1995) collected specimens of *Phialopecten* from the type section. In this study, collections have been made from the Wanganui River valley, Wairangi, the type section, Waitotara valley Road and State Highway 3 sections. To assist with interpretation, the general position within the shellbed of each of the collected species was noted (either lower, upper or throughout), as well as the relative abundance and state of preservation of the macrofauna. The collection of each species was classified into three semi-quantitative ranges, abundant (>15%), common (5-15%) and rare (<5%). Species noted in the field, but not collected were also included and their abundance noted. The data are presented in Appendix 2.

To estimate the paleodepth range in which the shellbed accumulated, the collections were compiled into an overall faunal list for each site, and most of the extinct species removed from the list. From the remaining list of the extant fauna, those taxa without known absolute modern depth ranges were discarded, and the depth ranges of the extant species within the shellbed were plotted on a floating bar graph for each locality. In some instances, a modern depth range was applied to an extinct species belonging to the same genus, where the similarities to the modern equivalent were high. Examples are the transfer of the depth ranges of *Pelicaria vermis* to the extinct species *Pelicaria* n.sp. aff. *zelandiae*; *Tawera spissa* for *Tawera subsulcata,* and *Zethalia zelandica* for *Zethalia coronata.* Depth ranges of molluscs were derived from Powell (1979), Beu & Maxwell (1990) and Morley & Hayward (2000). In this way, the minimum depth of deposition of the shellbed can be estimated from the shallowest of the plotted depth ranges, using species found only in the lower part or throughout the shellbed. The maximum water depth is derived from the overlap of the maximum and minimum depth ranges of species found in the upper parts or throughout the unit. However, the accuracy of the maximum depth ranges of the "shallower" molluscs is less than their minimums, because the shallow-water species are more susceptible to reworking into deeper water.

Distribution of species:

Figure 5.4 shows the distribution of several selected fossil mollusc species across the paleoshelf between the main sections investigated in this study. In the western sections, the faunal assemblage is dominated by shoreface taxa such as *Zethalia, Dosinia, Gari, Lutraria* and *Eumarcia,* which are abundant in the loose sand matrix in the lower part of the shellbed. The lack of these extremely shallow-water species in the upper part of the shellbed suggests that the depositional environment changed, becoming deeper and more affected by currents, as indicated by the harder substrate. As the fauna in the upper parts of the shellbed are not particularly diverse and has few modern correlatives, there is no direct evidence that the upper part of the shellbed is significantly deeper than the lower part, in sections westward of the type section. However, in the sections east of the type section (Wairangi and Wanganui), the occurrence of *Pelicaria* and *Pratulum* in the upper parts of the shellbed indicates a general deepening in that direction. In these eastern sections, none of the shoreface taxa occurring in the Waitotara valley sections are present. Another noticeable trend is the increase in pebble size from east to west, also indicating that a shoreline lay to the west.

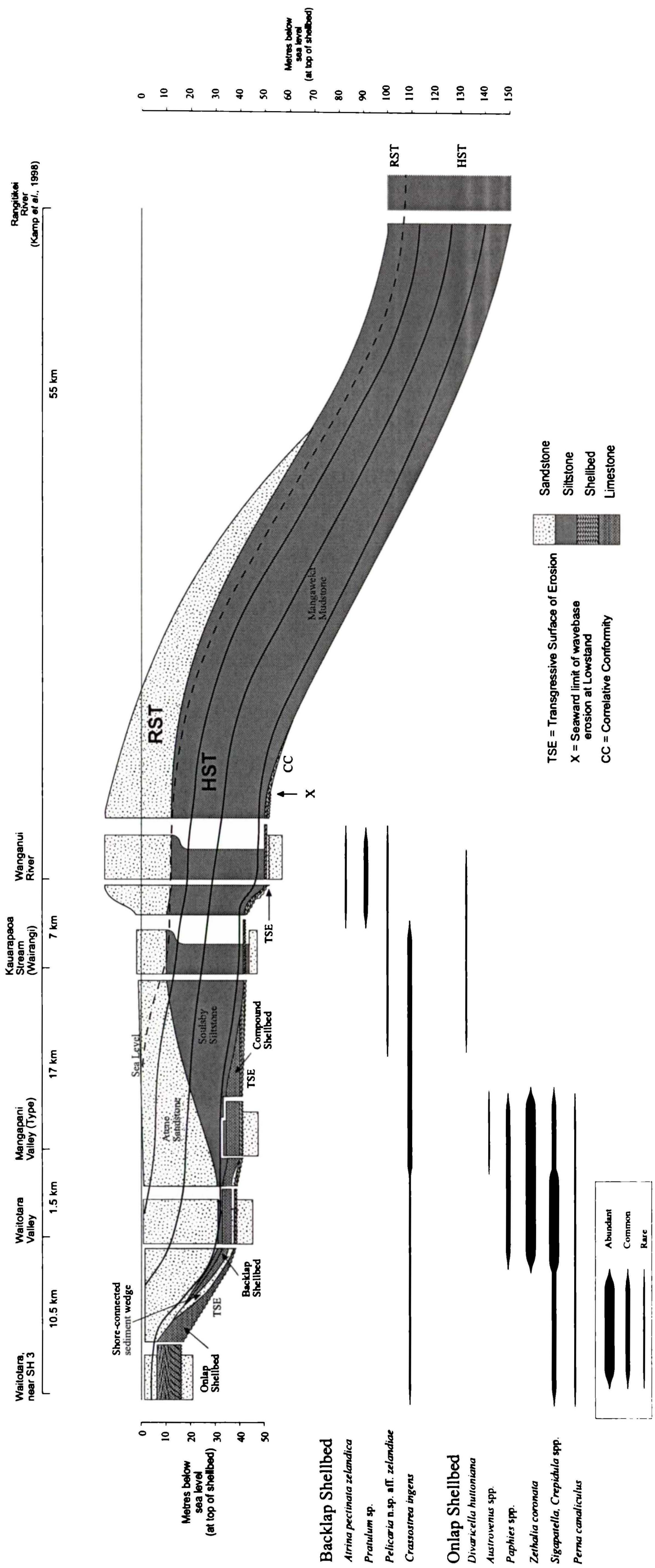


Figure 5.4: 2-D cross-section of the Mangapani Shell Conglomerate sequence showing the distribution of the main facies types, and below, the lateral distributio of macrofauna useful for determination of the paleobathymetry at the level of the Mangapani Shell Conglomerate and immediately overlying siltstone.

Paleobathymetry, Section by section:

Rangitikei River section:

The last occurrence of *Cibicides molestus* within the Mangaweka Mudstone allows a correlation to be made between the Rangitikei River section and the Mangapani Shell Conglomerate. The sample in the Rangitikei section containing the last occurrence of *Cibicides molestus* has an inferred paleodepth of ~ 150 m (Kamp *et al.,* 1998). 10 m stratigraphically above this horizon the inferred paleodepth is ~ 200 m. In this study, this deepening is correlated with the accumulation of the Mangapani Shell Conglomerate. The subsequent drop in sea-level is correlated with the accumulation of the Atene Sandstone in the western parts of the basin.

Wanganui River section: (Figure 5.5a)

Figure 5.5a shows the known and inferred depth range of selected species from the Mangapani Shell Conglomerate at Atene. The minimum depositional depth is estimated to be about 10 m, based on the dual occurrence of rare *Divaricella huttoniana* (max.depth = 10 m; Luckens, 1972; Beu & Maxwell, 1990) and *Pelicaria* n.sp. aff. *zelandiae* (min. depth = 10 m, max. = 50 m; Powell, 1979) near the base of the shellbed. However, this depth must be regarded as a minimum, because of the possibility of downslope reworking of *Divaricella.* The maximum depth of the unit is inferred from the maximum depth of *Pelicaria* n.sp. aff. *zelandiae* and the ocurrence of *Pratulum* sp. indicates a fine substrate, consistent with inner-mid shelf conditions in an open marine setting, whilst recognising it can occur in shallow estuarine muds A broad depth range of 30-50 m is estimated here for the top of the shellbed. Near the top of the Atene Sandstone in the bluffs above the Atene 'oxbow', flaser beds between the concretionary sandstone horizons indicate a return to extremely shallow marine water depths (upper shoreface-estuarine).

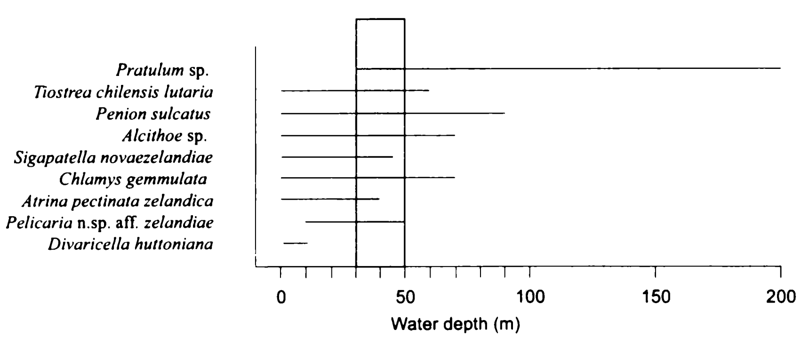


Figure 5.5a: Depth ranges of selected species, Mangapani Shell Conglomerate at Atene, Wanganui River valley. Shaded area represents the likely maximum water depth range indicated by the fauna for the top of the TST.

Kauarapaoa Stream (Wairangi) section: (Figure 5.5b)

The depth range of selected molluscs from the Mangapani Shell Conglomerate at Wairangi are shown in Figure 5.5b. The relatively low faunal diversity at this location means that the inferred depth range has a lower resolution that at other sites. However, a minimum depth of 0-10 m is inferred, based on the occurrence of *Divaricella huttoniana.* The maximum depth is taken to be 50 m, based on the occurrence of *Pelicaria* n.sp. aff. *zelandiae* in the siltstone immediately above the shellbed. Above the shellbed, the siliclastic units are inferred to progressively fine upsection, but a lack of faunal evidence and the inconsistency of the texture within the sandstone preclude any depth estimate from having a higher resolution than inner-shelf.

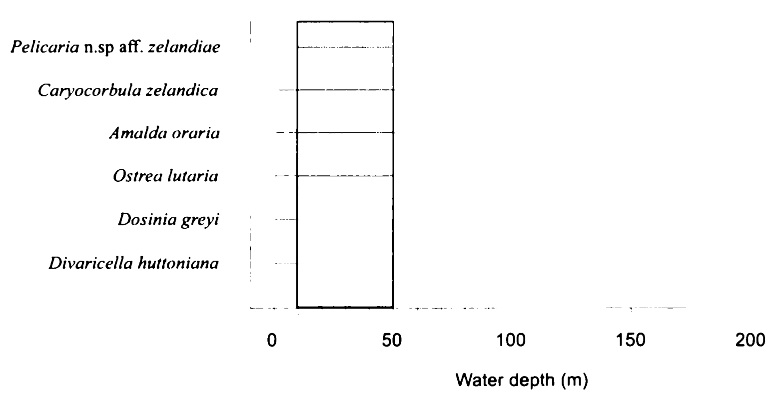


Figure 5.5b: Depth ranges of selected species, Mangapani Shell Conglomerate at Wairangi, Kauarapaoa valley. Shaded area represents the likely maximum water depth range indicated by the fauna for the top of the TST.

Mangapani valley (type section): (Figure 5.5c)

The diversity of macrofossils in the Mangapani Shell Conglomerate at the type section enables high resolution of the depositional depth of the Mangapani Shell Conglomerate at this locality (Figure 5.5c). The abundance of extremely shallow-water infaunal taxa (eg. *Zethalia, Gari, Austrovenus*) means that the minimum depth of deposition for the unit at its base was probably close to 0 m, deepening upwards to a maximum depth range of 30-45 m, indicated by the occurrence of *Evalea liricinta* (30-90 m, Powell, 1979), and *Sigapatella novaezelandiae* (0-45 m, Powell, 1979); the latter is common throughout the unit. As in other sections, the lack of a shellbed above the Atene Sandstone and its barren nature do not allow a more accurate estimate than inner shelf to be made for the environment of deposition of the Atene Sandstone.

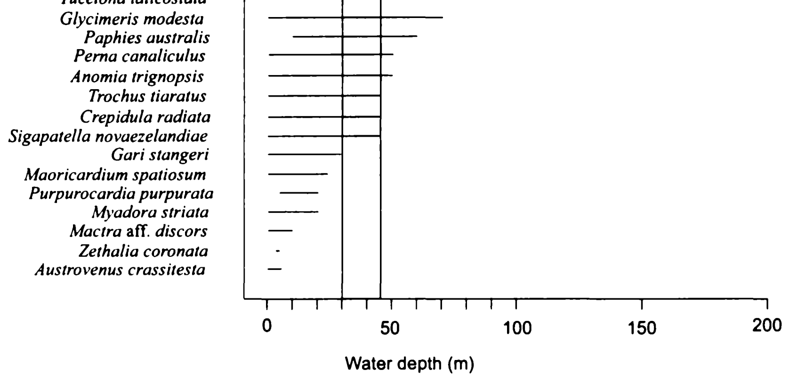


Figure 5.5c: Depth ranges of selected species, Mangapani Shell Conglomerate, Mangapunipuni valley (type section). Shaded area represents the likely maximum water depth range indicated by the fauna for the top of the TST.

Waitotara township (near SH 3): (Figure 5.5d)

Figure 5.5d shows the depth ranges of fossils in the Mangapani Shell Conglomerate at the Waitotara township locality, using faunal lists from Fleming (1953). The facies and faunal content suggest accumulation close to a rocky shoreline, with the fossil assemblage dominated by epifaunal species associated with a hard substrate. The cross-bedded nature of the unit indicates that it was deposited in a nearshore, high-energy environment, with an inferred minimum water depth of 0-5 m at the base of the shellbed, deepening upwards to a possible maximum of 20-30 m, based on the presence of *Ruditapes, Crepidula* and *Sigapatella* in the upper part of the unit. However, the obvious reworking precludes an accurate estimate of the maximum depth of deposition for this unit, although it seems unlikely to be any deeper than inner-shelf, proximal to a shoreface. The sandstone above the limestone is also inferred to be inner-shelf, based on its high sand content, and on the erosional contact on its upper surface.

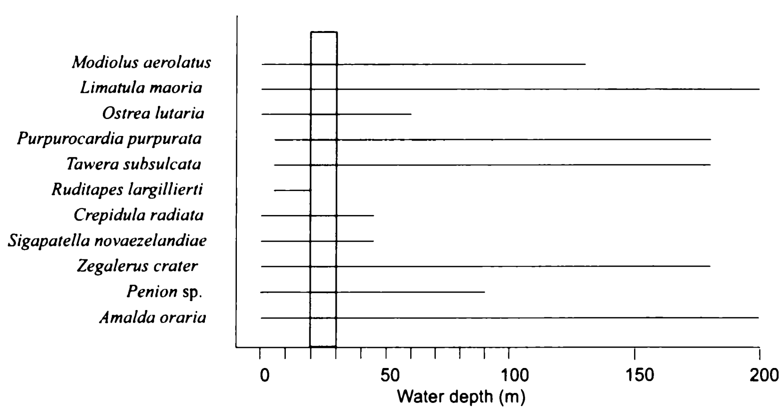


Figure 5.5d: Depth ranges of selected species, Mangapani Shell Conglomerate near SH3, Waitotara township. Shaded area represents the likely maximum water depth range indicated by the fauna for the top of the TST.

Paleobathymetric trends:

The trends in faunal composition for the Mangapani Shell Conglomerate across the basin show that the unit was deposited in progressively shallower water depths to the west (figure 5.4). In the Wanganui River valley, the faunal assemblage indicates of a maximum water depth near the inner–mid shelf boundary (about 40–50 m). The increasing faunal abundance and diversity to the west suggests closer proximity to the paleoshoreline, which is supported by the occurrence of shallow shoreface taxa such as *Gari, Paphies* and *Zethalia*, none of which occurs east of Mangapunipuni valley. Furthermore, occurrences of the comparatively deeper-water molluscs *Pelicaria* and *Atrina* are restricted to the easternmost sections. Figure 5.4 has been constructed by aligning the top of the Mangapani Shell Conglomerate for each stratigraphic section at its inferred water depth based on analysis of the molluscan content, as explained above. The depth of the Mangaweka Mudstone in the Rangitikei section is based on benthic foraminiferal paleoecology (Kamp *et al.*, 1998).

An unusual feature of the palinspastic reconstruction is the additional accommodation inferred for Atene Formation in the vicinity of Wanganui River. It appears that more sediment has accumulated than in neighbouring sections. While this feature could be due to a localised acceleration in the rate of tectonic subsidence that created additional accommodation at this locality, it probably is a feature common to most cyclothems at the lowstand shelf/slope break (see Chapter 8).

The total increase in water depth during the transgression in which the Mangapani Shell Conglomerate accumulated is estimated at 30-50 m, based on the faunal assemblage from the upper part of the shellbed. This estimate is believed to be fairly representative of the total increase in water depth for this transgression, because the poorly developed nature of the shellbed indicates that this locality was probably just submerged prior to the transgression, and thus the shellbed records all, or most of the transgression. This deepening from an inner-shelf depositional environment at the base of the shellbed to a inner-mid shelf setting at its top is matched by a contemporary increase in water depth from ~ 150 to ~ 200 m (from foraminiferal assemblages) within the Mangaweka Mudstone in the Rangitikei River section.

Facies trends:

The most notable facies parameter indicating westward shallowing of the depositional environment for the Mangapani Shell Conglomerate is the texture of the terrigenous material within the shellbed, and particularly the content of greywacke pebbles. They show a definite increase in abundance and size from the Wanganui River valley at Atene (5 mm), to 30 mm diameter in the Waitotara valley roadside section where they dominate the matrix in the lower part of the shellbed. Associated with this increase in pebble size is a change in the siliciclastic matrix of the shellbeds. This matrix coarsens westwards from a sandy siltstone at Atene, to sandy fine gravel in the SH3 section near Waitotara, where the high-angle cross-beds, abraded shell material, and abnormal thickness are all consistent with a high-energy shoreface depositional environment. The thickness of the shellbed also increases westward, and the combined thickness of the overlying siliciclastic units (Soulsby Siltstone and Atene Sandstone) thins westwards. The preservation and abundance of fossils within the shellbed also reveals a westwards shallowing trend. The highest abundance of shell material is in the SH3 section near Waitotara, where the carbonate is highly abraded and reworked. Faunal preservation improves eastwards across the paleoshelf, and is accompanied by a thinning of the shellbed, with less overall shell material present. This pattern continues eastwards to Atene, where the shellbed contains a very sparse faunal assemblage, which is dominantly *in situ*. At the stratigraphic equivalent of the shellbed within the Mangaweka Mudstone in the Rangitikei River section, no molluscan fauna is present, no bedding structures are visible, and the fine siltstone facies represent a low-energy outer-shelf to upper-slope depositional environment.

Sequence Stratigraphic Interpretation.

The depositional depth analysis undertaken for the sections across Wanganui Basin shows that the Mangapani Shell Conglomerate is a transgressive deposit resulting from a eustatic sea-level rise of about 50 m. The same data indicate that the transgression was probably directed westwards towards the Patea-Tongaporutu High. The paleoshelf transect reconstructed from the various sections may not have been oriented shore-normal. The inner part of the shelf experienced a 50 m increase in water depth associated with the transgression over a horizontal distance of 36 km, giving a gradient of 0.00002°.

While the depositional depth and paleogeographic evidence extracted from molluscs reveals a general pattern of deposition for the Mangapani Shell Conglomerate, a much more detailed evolution of the cyclothem can be obtained by overlaying a sequence stratigraphic template on units and features observed in the field. This relies on the identification of key surfaces, the most fundamental being the sequence boundary (SB), which in this case corresponds to the stratal contact between two cyclothems. Here, a sequence boundary is placed at the lower contact of the Mangapani Shell Conglomerate, and another at the top of the Atene Sandstone. The lower sequence boundary is unconformable with the underlying Waverley Formation sandstone wherever the Mangapani Shell Conglomerate was observed, and thus is also a transgressive surface of erosion (TSE). Another key surface is the downlap surface (DLS of Naish & Kamp, 1997), which separates the transgressive from regressive phases of the depositional system, and in this case occurs immediately above the Mangapani Shell Conglomerate. Here there is a rapid reduction in grainsize, accompanied by a change from carbonate-dominated facies to terrigenous facies. No evidence for a regressive surface of erosion (RSE) (e.g. Plint, 1998) exists in this study, so it is not applied here.

The Mangapani Shell Conglomerate itself is a transgressive systems tract (TST), consistent with a *base-of-cycle* coquina in the sense of Kidwell (1991), with a condensed composite concentration of molluscs overlying a transgressive surface. Kidwell (1991) identified four different styles of stratigraphic condensation resulting in carbonate accumulation on the continental shelf during eustacy; *marine onlap, backstep, downlap* and *toplap*, all of which relate to various depositional contexts (Fig 5.6). Naish & Kamp (1997) modified these designations and applied them to late Pliocene–early Pleistocene shellbeds in Rangitikei valley, with the terms *onlap* and *backlap* shellbeds representing transgressive deposit lithologies, and *downlap* and *toplap* shellbeds being units formed during regression. This work also introduced the term *compound* shellbed, which referred to the superposition of the onlap, backlap and elements of the downlap shellbeds in relatively deep, offshore settings. The position of these shellbeds in relation to their associated systems tracts is shown conceptually in figure 5.7.

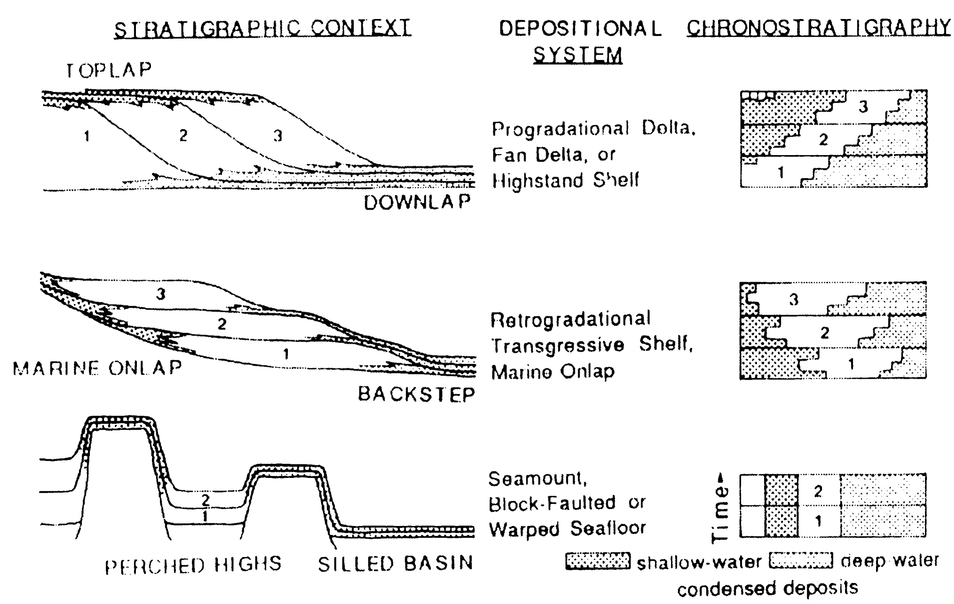


Figure 5.6: Depositional settings in which condensation and subsequent carbonate production is common on the marine shelf. Shallow water examples involve physical winnowing and reworking while deeper water settings are the result of sediment starvation. (From Kidwell, 1991).

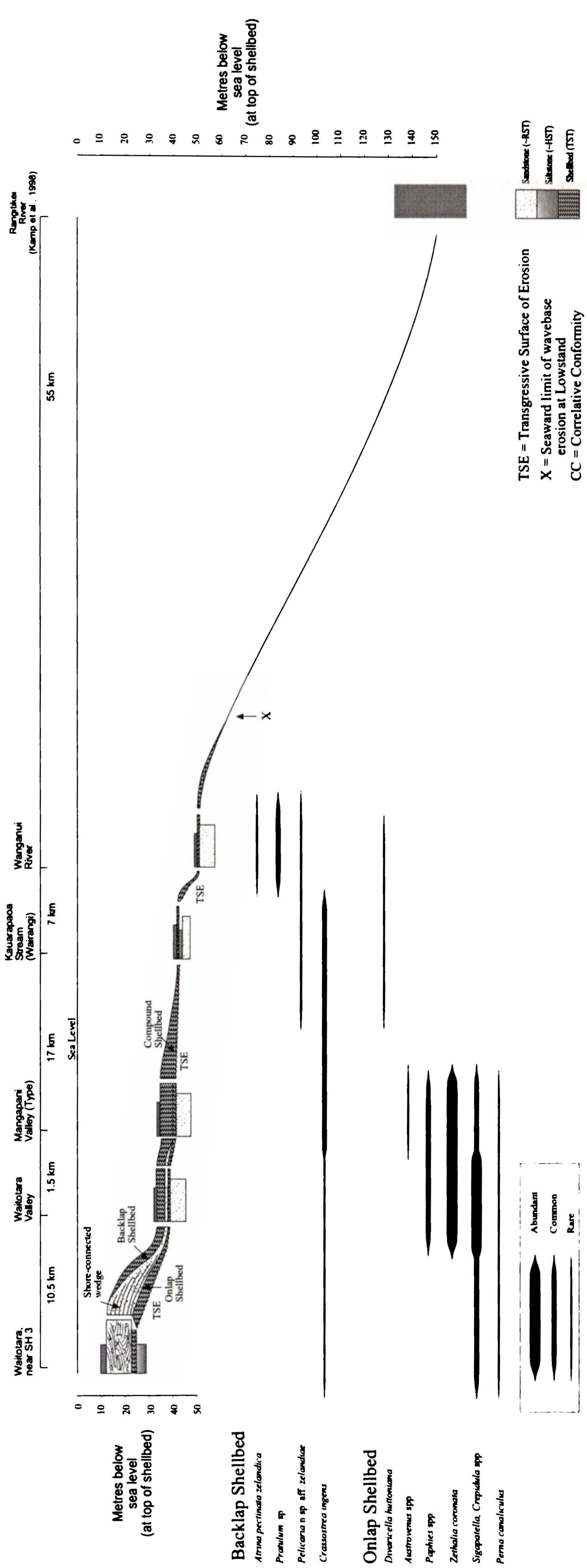


Figure 5.7: Mangapani Shell Conglomerate, cross-shelf facies patterns and distribution of shellbeds comprising the TST. This figure also shows the abundance of selected fossil molluscs in the onlap and backlap shellbeds. The vertical axis on the cross-section is water depth at the top of the TST.

The following sections provide a sequence stratigraphic interpretation of the cyclothem comprising the Mangapani Shell Conglomerate, Soulsby Siltstone, and Atene Sandstone.

Transgressive System Tract:

Onlap Shellbed:

The onlap shellbed part of the Mangapani Shell Conglomerate (Figure 5.7) includes the bivalve-dominated, aragonitic shells that occur at the base of the unit in and westwards of the type section at Mangapunipuni valley. The onlap shellbed has an eroded base, the sharp contact (TSE) having formed by wave–planation of the underlying sediments during the marine transgression. Typically, the matrix of the onlap shellbed is coarse, with the largest pebbles and coarsest sand matrix of the unit occurring in this part of the shellbed. Molluscs in the onlap shellbed are densely packed and current bedded, dominated by disarticulated bivalves oriented convex–upward, in a hydrodynamically stable position. Infaunal taxa such as *Gari, Zethalia, Paphies, Polinices, Tawera* and *Tucetona* are common in the onlap part of the shellbed. From the state of preservation and characteristics of the assemblage of the fauna in the onlap shellbed, a maximum water depth approximately equivalent to the deeper limit of wave–base turbulence is inferred. This means that the onlap shellbed is associated with the early part of the transgression, spanning the initial flooding (0 m) to about 10–15 m water depth. In the westernmost section near SH3 at Waitotara, the entire Mangapani Shell Conglomerate / Limestone is considered to be an onlap shellbed, because of its highly abraded and cross-bedded nature, and the lack of in-near *situ* fauna in the unit.

Backlap Shellbed:

The *Phialopecten thomsoni*-dominated limestone part of the Mangapani Shell Conglomerate is interpreted as a backlap shellbed, which differs from the onlap shellbed in being comprised of calcitic species, having a better state of preservation, and having had a deeper-water depositional environment. It is best developed near the type section in the Mangapunipuni and Waitotara valleys, where it reaches thicknesses of 5 and 2.5 m respectively. No backlap shellbed is present in the SH3 section at Waitotara, but exposures of the unit near Ngutuwera (R22/577583) have an upper, *Crassostrea*-dominated part, which is interpreted as probably being a backlap shellbed. Features consistent with a backlap shellbed include a deeper-water faunal assemblage dominated by epifaunal, calcitic species such as *Phialopecten, Crassostrea* and *Atrina.* However, in contrast to the description of the backlap shellbed of Naish & Kamp (1997), the fauna in the backlap part of the Mangapani Shell Conglomerate is much less diverse than in the onlap shellbed, and is not *in situ*. This is possibly due to the relatively small amplitude of sea–level rise compared with the Nukumaruan-Castlecliffian cyclothems, allowing a more energetic inner–mid shelf environmental niche to be sustained in which *Phialopecten* flourished. This interpretation is supported by the presence of pebbles in the backlap shellbed. While being smaller than those in the onlap, nevertheless indicate that the backlap shellbed in this case incorporates elements consistent with a shell lag deposit. Kidwell (1991) showed that a backlap (or backstep) shellbed migrates shoreward on the distal and upper surface of the siliciclastic TST deposits (shore-connected-wedge, see below), and thus does not extend to the shoreline. This possibly explains why the whole of the Mangapani Shell Conglomerate in the SH3 section is an onlap shellbed. The westernmost occurrence of the backlap shellbed pinches out to the east of this section.

Shore–connected Transgressive Sediment Wedge:

This terrigenous unit is best observed separating the onlap and backlap parts of the Mangapani Shell Conglomerate in Waitotara valley, where it is represented by the 1.4 m-thick, barren sandstone with siltstone laminations. The absence of both pebbles and molluscs from the unit indicates a period of sedimentation between the basinward limit of onlap condensation and the shoreward extent of backlap condensation during transgression (Figure 5.7). The highly bedded nature of this unit is characteristic of terrigenous TST deposits, and probably reflects the retrogradational fashion in which the unit was deposited, in horizontally oriented thin sedimentary 'packets' as opposed to the thick offlapping clinoforms associated with regressive systems tracts. The shore-connected wedge was deposited during onlap, as wave and current action winnowed the sand-silt particles basinward, leaving the coarser-grained pebbles and molluscs in the higher-energy shoreface environment. As the transgression continued, the area of terrigenous deposition moved shoreward, and the decreasing rate of sedimentation permitted a backlap shellbed also to move shoreward, forming on top of the shore-connected wedge.

Compound Shellbed:

A compound shellbed is one where the onlap and backlap components are superimposed. The Mangapani Shell Conglomerate in both the Mangapunipuni valley and Wairangi sections is therefore a compound shellbed, with the outcrop at the former locality having a more dramatic facies and faunal contrast between the onlap and backlap parts than at the latter. At Wairangi, the compound nature of the shellbed is evident in the faunal assemblage, with shoreface molluscs such as *Divaricella* and *Dosinia* in the base of the shellbed grading upwards into relatively deeper water forms (*Crassostrea, Amalda).* A weakly fossiliferous compound shellbed is inferred to have been present in the Wanganui River section, but is now indistinguishable from the underlying regressive sandstone, probably because of leaching. However, the omission surface (possibly even a TSE) seen 30 cm below the very top of the sandstone is interpreted as the sequence boundary, with very little shell material present.

Highstand System Tract:

Highstand terrigenous units:

The siliciclastic units observed directly above the shellbeds comprising the Mangapani Shell Conglomerate have the finest-grained facies in the sequence, and are interpreted as having been deposited during maximum sea–level flooding. Furthermore, the abrupt decrease in macrofossil abundance signals an accelerated rate of terrigenous sediment deposition as the rise of relative sea-level slowed and stratigraphic condensation ceased. This rapid, conformable change in facies is interpreted as the downlap surface (DLS), and the siliciclastic units above it are part of a highstand systems tract (HST). As the definition of an HST is applied to sediments deposited "during the late part of a eustatic sea–level rise, a eustatic stillstand, and the early part of a eustatic fall" (Van Wagoner *et al.*, 1988), the base of the HST can be positioned at the top of the shellbed, or in sections where a downlap shellbed (see below) is present, between the backlap and downlap shellbeds. The top of the HST cannot be located precisely in any of these sections because no suitable surface marking the boundary between the HST and overlying RST (regressive systems tract) can be found. The gradual upsection coarsening of grainsize from siltstone to sandstone within the upper siliciclastic units is diachronus. However, the sandstone at the top of the sequence at Atene is probably an RST deposit. This interpretation is explained in Chapter 8.

Downlap Shellbed:

Downlap shellbeds occur above the compound Mangapani Shell Conglomerate in the Wairangi and Wanganui River sections. At Wairangi, the downlap shellbed is represented by rare *in situ Pelicaria* in the lower 2 m of the siltstone overlying the main onlap and backlap shellbeds. In the Wanganui River section it is more fossiliferous, represented by about 2 m of fossiliferous siltstone resting conformably on sandstone, a contact interpreted as the downlap surface. The faunal assemblage is consistent with condensation at a point in the basinward toe of the prograding siltstone, with relatively deep-water molluscs such as *Penion, Pelicaria, Alcithoe* and *Pratulum* present. Thus, the downlap shellbed is not a transgressive deposit, but is part of the highstand systems tract.

Regressive Systems Tract:

The regressive systems tract (RST) of Naish & Kamp (1997) is applied in this study, referring to those sediments deposited during the middle stages of regression, when the rate of eustatic fall exceeds that of basin subsidence, and accommodation is progressively reduced. Because only sediments deposited during the late stages of sea–level fall can be placed in an RST, those sediments deposited proximal to the maximum flooding shoreline cannot be included in an RST, but must be placed into an HST, regardless of their facies or grainsize. It is likely that the Atene Sandstone in the more central parts of the basin is part of the RST, as explained in Chapter 8. However, the boundary between HST and RST sediments cannot be identified within this succession, because there is no stratal horizon which marks the HST / RST transition. The siltstone / sandstone boundary is diachronus, and therefore unsuitable for such a surface. However, the likely position of the HST / RST transition is plotted as a dashed boundary on figure 5.4.

Distribution and positioning of shellbeds into systems tracts:

As predicted by Naish & Kamp (1997), the relative positioning of the shellbeds within the systems tracts comprising a cyclothem varies both vertically and laterally. A summary of the type of shellbeds found in each of the studied section reveals this pattern. The table below is a simple description and sequence stratigraphic interpretation of the units comprising the transgressive and highstand systems tracts in each of the five main sections in which the Mangapani Shell Conglomerate crops out. Where present, the type of shellbed is displayed in italics, with terrigenous units included where no shellbed occurs. The focus of this table is in the internal stratigraphy of the shellbed itself and the nature of the contact at the sequence boundary beneath, with the upper part of the HST and the entire RST not displayed.

Table 5.2: Cross-basin occurrence of onlap, backlap, compound and downlap shellbeds, within the Mangapani Shell Conglomerate. (SCW = Shore-connected sediment wedge).

<table>
<tr><th>Sys-
tems
Tract</th><th>Wanganui</th><th>Wairangi</th><th colspan="2">Mangapani (type)</th><th>Waitotara</th><th>SH3</th></tr>
<tr><td>HST</td><td>Downlap</td><td>Downlap</td><td colspan="2">Siltstone</td><td>Siltstone</td><td>Sandstone</td></tr>
<tr><td rowspan="3">TST</td><td rowspan="3">Faunally impoverished silty sandstone
(Compound)</td><td rowspan="3">Compound</td><td rowspan="3">(Compound)</td><td rowspan="2">Back-
lap</td><td>Backlap</td><td rowspan="3">Onlap</td></tr>
<tr><td>SCW</td></tr>
<tr><td>Onlap</td><td>Onlap</td></tr>
<tr><td>Contact</td><td>Unconformity</td><td>Unconformity</td><td colspan="2">Unconformity</td><td>Unconformity</td><td>Unconformity</td></tr>
</table>

This pattern shows that each of the shellbeds occurs in its predicted paleoshelf position. An onlap shellbed is the only shellbed comprising the Mangapani Shell Conglomerate west of the Waitotara valley section. This figure shows that all onlap shellbeds and at least some compound shellbeds have erosional bases. Above the onlap shellbed, the shore–connected transgressive sediment wedge can occur (i) separating the onlap shellbed from the backlap shellbed. (ii) marking the top of the TST (a motif not seen in this study but predicted), or (iii) absent from sections most proximal to the paleoshoreline, where backlap condensation did not exist. The compound shellbed part of the Mangapani Shell Conglomerate shows considerable variation, becoming thinner, less fossiliferous and more homogeneous basinward. The restriction of the downlap shellbed to sections containing only a compound shellbed is consistent with the interpretation of the shellbed as being part of a progradational highstand systems tract.

Two-dimensional reconstruction of entire cyclothem:

Figure 5.4 shows the distribution of the main constituents of the cyclothem across the shelf in cross–section. Between sections, the most likely intervening geology has been added, to show a near–continuous cross–shelf profile. A few time lines have been plotted on the figure to try and isolate the positioning of systems tracts, but their placement on the figure does not necessarily mimic any systems tract boundaries. The time lines illustrate the diachronous nature of faces within the cyclothem, as they must cross facies boundaries in order to parallel the lower and upper sequence boundaries. This means that certain faces are not synonymous with systems tracts. The lowermost systems tract in the figure, the TST (represented by the onlap and backlap shellbeds, clearly thins basinwards, and becomes less coarse grained, grading from shellbeds set in a conglomerate–sandstone matrix to outer shelf siltstones in the east. The boundary between the TST and HST cannot be accurately located on this figure, but is considered to be in roughly the same position as the lower timeline shown. The HST shows a similar basinwards-fining trend, with highstand sandstone in the west grading laterally into siltstone. The top of the HST is not defined by any stratal surface, and is not accurately plotted on this figure, but would parallel the timeline near the top of the succession. The RST sediments are also not closely defined on this figure, but must be stratigraphically above and basinward of the HST, which places them in the upper part of the terrigenous units. As with the other systems tracts, the RST also fines basinward.

Modelling the Mangapani Shell Conglomerate.

Following the method of forward modelling of cyclothems established by Kamp & Naish (1997), the depositional history of the cyclothem containing the Mangapani Shell Conglomerate can be reconstructed. This method involves the quantification and integration of the simultaneous processes required for the formation of a cyclothem. These include the rate and amplitude of sea–level rise, the rate of subsidence and the sedimentation rate.

Sea–level change:

To accurately predict the nature and amplitude of the actual sea–level rise and fall associated with the formation of the cyclothem containing the Mangapani Shell Conglomerate, it is necessary to correlate the cyclothem with the oxygen isotope timescale. As previously stated, the Mangapani Shell Conglomerate is correlated with the inferred sea–level rise from Oxygen Isotope Stages G10 to G9, a glacial–interglacial progression with a $\delta^{18}O/\delta^{16}O$ shift of around 0.7‰ in the equatorial eastern Pacific Ocean (Shackleton *et al,* 1995) to 0.8‰ for the eastern equatorial Atlantic (Tiedemann *et al.,* 1994). Using the proposal of Raymo *et al.* (1989) that the 2/3: 1/3 ice volume : temperature ratio partitioning of the $\delta^{18}O$ signal developed in the Pleistocene is also applicable to the late Pliocene, the $\delta^{18}O$ to sea–level calibration of 0.11‰ per 10 m of Fairbanks & Matthews (1978) allows an estimate of the amplitude of sea–level rise associated with these isotope stages. In this case, of the 0.7‰ $\delta^{18}O$ shift from stages G10 to G9 from ODP Site 846 (Shackleton *et al.,* 1995), 2/3 (0.47‰) is attributed to sea–level rise. Using the factor of 0.11‰ per 10 m of sea–level rise, it is estimated that the rise in sea–level between isotope stages G10 and G9 was 43 metres.

Sediment accumulation rate:

Using the paleomagnetic timescale established in the Wanganui River valley, an estimate of the rate of sediment accumulation for the upper part of the Gauss Chron (C2An.1n) based on the 900 metres of section between the top of the Kaena subchron (3.032 Ma) and the Gauss / Matuyama boundary (2.582 Ma: both dates from Lourens *et al.,* 1996) give a minimum sediment accumulation rate of 1.9 $m.ky^{-1}$.

Assuming that the cyclothem containing the Mangapani Shell Conglomerate is a composite of two cycles of 41 k.y. duration (based on the dominant Milankovitch obliquity parameter in the Pliocene), the thickness of the cyclothem in the Wanganui River valley (92 metres) means that the rate of net sediment accumulation was 1.1 $m.ka^{-1}$. The difference between the two values indicates that the net rate of sediment accumulation for the cyclothem was considerably less than for the Taihape and Mangaweka Mudstones. This is not unexpected given the disparity in available accommodation inferred by the facies of the Atene Formation sediments. However, the marked disparity between the thicknesses of the three cyclothems comprising the Atene Formation suggests that the rate of sediment accumulation varied for each; the lower and upper cyclothems in the formation therefore have sediment accumulation rates of 0.7 and 1.6 $m.ky^{-1}$ respectively.

Subsidence rate:

The major facies change from the Atene Formation into the overlying Mangaweka Mudstone in the Wanganui River valley is regarded as originating from a tectonic pull–down, involving a deepening of about 100 m (Hayton, 1998). This means that the subsidence rate for this part of the Wanganui Basin was not linear, and the shallowing upwards trend observed in these larger scale cycles shows that that the rate of subsidence was less than the rate of sediment accumulation. For the 82 k.y. interval in which the Mangapani Shell Conglomerate and its associated cyclothem/s were formed, the rate of subsidence is assumed to have been equal to the net rate of sediment accumulation, with 0.7 $m.ky^{-1}$ and 1.6 $m.ky^{-1}$ for the lower and upper parts of the cyclothem respectively.

Modelling the Mangapani Shell Conglomerate, Wanganui River valley.

A model for the deposition of the cyclothem containing the Mangapani Shell Conglomerate in the Wanganui River valley is presented in figure 5.8. The correlation with the oxygen isotope timescale (from ODP Site 846) used for the model is also shown. The model target bathymetry is based on the molluscan paleobathymetry (see above). The model differs from the single–cyclothem versions of Kamp & Naish (1998) in that it involves multiple isotope stages, and the rate of subsidence varies during the deposition of the formation. Here, the increase in grain size within the siltstone above the shellbed is correlated with the relatively small $\delta^{18}O$ shift of Stage G8, and Stages G6 and G4 with the two sandy horizons occurring in the upper part of the Atene Formation.

The differences in the sea–level rise between Stages G10 and G9 as predicted by the model compared with the molluscan paleobathymetry suggests that in this case the shellbed does not accurately represent the full extent of the TST, which possibly extends further upsection into the siltstone. However, the low faunal abundance and diversity in this particular section does not allow a high resolution for the molluscan paleodepth estimate, based on the overlap of the ecological depth ranges of only two species. The sharp–based break in the sandstone underlying the fossiliferous siltstone is interpreted here as a TSE, with the rare *Divaricella* in the TST sandstone inferring a paleodepth of up to 10 m, the depth used as the existing bathymetry at the sea–level lowstand. The model predicts that the combination of subsidence and eustacy resulted in a maximum water depth of 67 m, made up of 14 m of subsidence (half of 27 m), 43 m of glacio–eustatic sea–level rise, and 10 m of existing bathymetry.

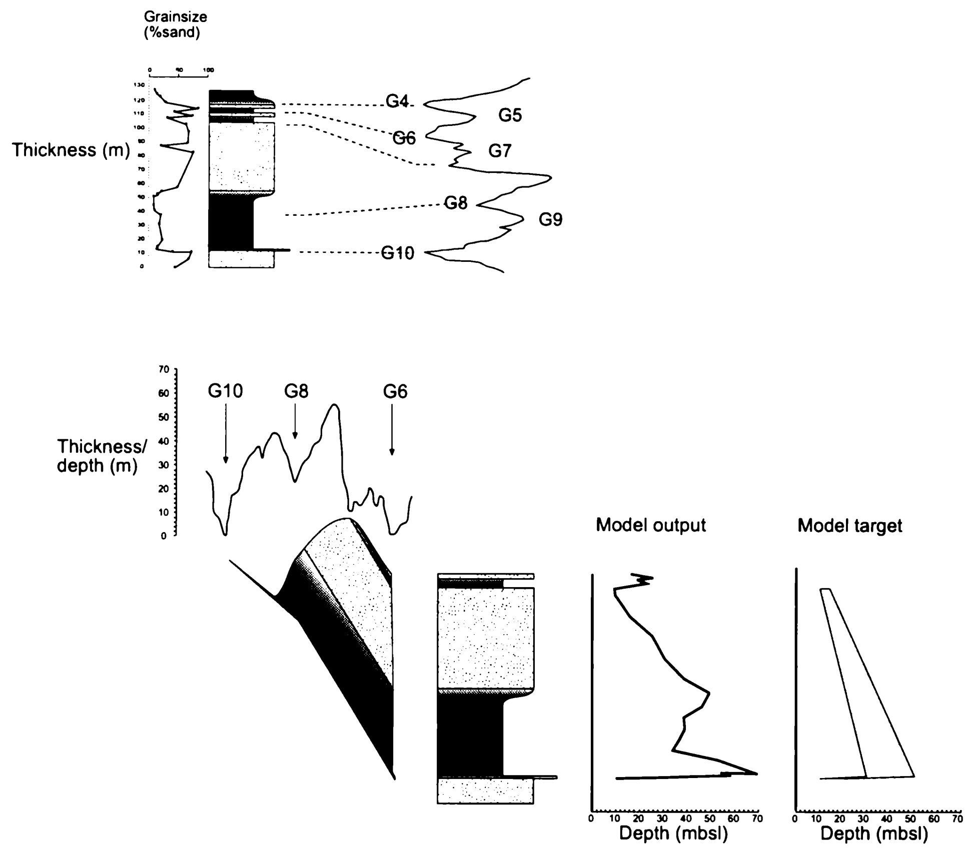


Figure 5.8: Model for the depositional history of the Atene Formation, Wanganui River section, based on the 2D modeling method developed by Kamp & Naish (1997).

Discussion.

The outcrop belt of the Mangapani Shell Conglomerate (at least 36 km in length) shows that the shellbed is a regional feature, which is consistent with the hypothesis that it represents a transgressive deposit associated with a significant sea–level rise. This transgression is probably glacio–eustatically controlled, based on the known magnitude and periodicity of sea–level change through the Plio–Pleistocene. However, there does not appear to be any fossil evidence for temperature change during deposition of the cylothem, which would normally be expected in an alternating glacial–interglacial succession. This lack of evidence for noticeable temperature change in the faunal assemblages within a cyclothem is a feature common with almost all Plio-Pleistocene New Zealand cyclothemic successions (Beu & Kitamura, 1998).

The correlation of Oxygen Isotope Stages G10–G9 with the shellbed is based on the counting of cycles within the constraints of a paleomagnetic record and a few numerical ages for tephra. The 2.79 Ma age we assign to the Mangapani Shell Conglomerate based on linear interpolation between the top of the Kaena subchron (3.032 Ma) and the Gauss/ Matuyama reversal (2.582 Ma) (ages from Lourens *et al.,* 1996) closely matches the age and assignment of the major $\delta^{18}O$ shifts between Stages G10–G9. Furthermore, the upwards coarsening from siltstone to sandstone above the shellbed is consistent with the relatively small $\delta^{18}O$ shift into Stage G8. The siltstone–sandstone perturbations at the top of the Atene Formation are correlated with the low-amplitude $\delta^{18}O$ shifts between Stages G8, G6 and G4. This date for the Mangapani Shell Conglomerate differs significantly (~ 200 k.y. younger) from the previously assigned age of 3.03 Ma of Beu (2001), which reflects the age offset between the FO of dextral *Globorotalia crassaformis* and the benthic foraminiferal and molluscan bioevents at the Waipipian / Mangapanian Stage boundary. A correlation between these two separate event horizons can be made with the Pliocene stepwise climatic cooling between ~ 3.2 Ma and ~ 2.7 Ma suggested by Kennett (1995). This was attempted by Beu (1995), based on the dates 3.2 Ma and 2.7 Ma approximating the Waipipian / Mangapanian and Mangapanian / Nukumaruan Stage boundaries. Here, we correlate the first event with the coiling change in *G. crassaformis*, and the second with the Waipipian / Mangapanian Stage boundary, where 14.2% of New Zealand molluscan genera became extinct (Beu & Maxwell, 1990), and the pecten *Phialopecten marwicki* evolved rapidly into *P. thomsoni* (Beu, 1995).

An advantage in studying the Mangapani Shell Conglomerate as opposed to one of the many other shellbeds in the Waipipian / Mangapanian Stages in Wanganui Basin is that it displays the most dramatic shoreline to basin deepening trend of any of these shellbeds, with the highest resolution of outcrop, both laterally and vertically. While the Wilkies and Hautawa Shellbeds and their associated cyclothems also display a similar trend, the

Mangapani Shell Conglomerate has more internal microstratigraphical detail in its TST, and also represents a greater variety of shelf positions across its outcrop transect. However, greater resolution of this transect is possible than presented here, and sections between the Waitotara valley Road and SH3 sections could potentially reveal exactly what happens to the shore-connected-wedge and backlap shellbeds between these two sections.

Within this cyclothem, the general pattern of the facies and faunal assemblages means that the Mangapani Shell Conglomerate accumulated during a generally westward-directed transgression, although it is unknown at what angle across the paleoshelf the outcrop transect lies. The nature and positioning of the types of shellbed within the TST (Kidwell, 1991; Kamp & Naish, 1997) confirms that they are laterally extensive, and each represents different stratigraphic contexts. In this example, the onlap shellbed is always underlain by a TSE, which is also the case with the shoreward expression of the compound shellbed. The basinward extent of the TSE was not observed, so the point at which the base of the cyclothem becomes conformable (Point "X") must be somewhere between the Wanganui and Whangaehu River valleys. The shore–connected sediment wedge was observed only where it separated definite onlap and backlap shellbeds.

The pebbles within the Mangapani Shell Conglomerate have no obvious origin within the basin. One possibility is a local paleohigh, but their highly rounded condition means that their source cannot have been proximal to their depositional site. A potential source is the Patea-Tongaporutu basement high, which was possibly emergent at this time somewhere to the southwest of the study area. Alternatively, and more probably, they could have come from a South Island source. This possibility is supported by the occurrence of rare schist pebbles in strata below the Mangapani Shell Conglomerate in the Waitotara River section.

CHAPTER SIX:

THE WILKIES SHELLBED: A LATE PLIOCENE BIOSTROME PLACED IN A SEQUENCE STRATIGRAPHIC CONTEXT.

Introduction.

History:

The Wilkies Shellbed can be regarded as the thickest and most distinctive shellbed in the Wanganui Basin succession. It is also considered to be the largest single accumulation of fossil shells known in New Zealand (Beu & Maxwell, 1990). It is readily discernible from other shell-beds in the basin by the abnormal thickness of coquina containing the extinct giant oyster *Crassostrea ingens*, which form large "reefs" up to 15 m thick in places. The formal taxonomic description of *Crassostrea ingens* was made by Zittel (1864), who loosely described the locality from which the type specimen was collected as "Wanganui River", which almost certainly refers to the Wilkies Shellbed at Te Rimu, several kilometres north of Parikino (Enclosure 2). Because of its uniqueness, the shellbed has a relatively long history of reference in New Zealand geological literature and elsewhere.

The earliest definite reference to the shellbed, which subsequently became known as the Wilkies Shellbed, was that of Park (1887), who collected from and described the "Shellbed near the mouth of the Waitotara River, opposite Wilkies Farm" on the true left bank of the Waitotara River, about 2km upstream of the river mouth. He loosely correlated it with the shellbeds at Parikino, as part of his "Upper Miocene Coralline Series". Park made further modifications to the nomenclature of his Wanganui "System" in 1905 and 1910, which placed the shellbed as a unit within the "Older Pliocene Waitotara crags" of the Waitotara Series. Thomson (1916) introduced the New Zealand Stage system, and using Park's data, subdivided the New Zealand Pliocene into two parts, the Castlecliffian (upper) and Waitotaran (lower).

Marshall & Murdoch (1920) in a paleontological study of the Castlecliff, Kai-Iwi, Nukumaru and Waipipi Beach sections concluded that the shellbed at Wilkies Bluff was faunally distinct compared with their collections from the Waipipi and Nukumaru Beach strata, and formed a connecting-link between these two sections, but did not use these data to modify the basic stratigraphic framework erected by Park (1910). Using these data as a basis, Morgan (1924) subdivided the two stages into three, with the "Castlecliffian" remaining unchanged, but the "Waitotaran" being split into two parts, an overlying Nukumaruan Stage and an underlying Waipipian Stage. The term "Waipipian" soon informally reverted back to "Waitotaran", and this general usage of Castlecliffian, Nukumaruan and Waitotaran, comprising the three stages of the Wanganui Series persisted until Finlay (1939) added a lowermost fourth stage, the Opoitian Stage (Fleming, 1953).

The next notable investigation to include the distinctiveness of the shellbed at Wilkies Bluff was Laws (1940), who collected fossil molluscs from Nukumaru Beach, Wilkies Bluff, Mangapani valley, Waipipi and Waihi Beaches. He demonstrated a close similarity in the faunal assemblage between the shellbeds at Wilkies Bluff and Mangapani valley. Statistically, he concluded that these three shellbeds all belonged in the Nukumaruan Stage, with the Waipipi and Waihi Beach sections being Waitotaran. When Fleming (1947; p. 301) formally defined the base of the Nukumaruan Stage in the coastal section at the base of the Nukumaru Limestones, the shellbed at Wilkies Bluff reverted back to being part of the Waitotaran Stage, with Fleming (1947) designating Wilkies Bluff as the type section for the Waitotaran Stage.

Meanwhile, Feldmeyer *et al.* (1943) made the first broad correlations of strata in central to eastern parts of Wanganui Basin. The correlations were based on foraminiferal biostratigraphy, but the occurrence of a thick *Crassostrea* shell "reef", clearly the Wilkies Shellbed, was included in the Wanganui River valley stratigraphic column.

The "Shellbed at Wilkies Bluff" was formally named the "Wilkies Shellbed" by Fleming (1953) and given formation status. In that study the Wilkies Shellbed was correlated to the east in inland river valley sections where there are spectacular occurrences. Nine new collections of the shellbed were made by Fleming (1953) between the type locality at the Waitotara River mouth and the Parihauhau valley, a distance of 45 km. This substantial work contributed greatly to the understanding of the stratigraphy of the Wanganui Basin, especially regarding strata of the "Waitotaran Stage", which are poorly exposed on the coastal section between Nukumaru and Waipipi. The description of many new inland sections together with many fossil mollusc collections formed the basis of a new, comprehensive basin stratigraphy and molluscan biostratigraphy. Fleming's discovery of multiple bioevents at certain stratigraphic horizons allowed accurate and formal definition of stages in the Wanganui Series. He subdivided the Waitotaran Stage into two substages. The Mangapanian Substage was defined for strata including the Mangapani Shell Conglomerate up to the base of the Hautawa Shellbed. The Waipipian Substage was defined for strata beneath the Mangapani Shell Conglomerate, with the base of the substage not reached in the study, and therefore not defined. Subsequently, the Waitotaran Stage has been abandoned, and the Mangapanian and Waipipian Stages now enjoy full stage status (Beu, 1969; 1970; 1995). Fleming (1953) located the Wilkies Shellbed within the Mangapanian Substage, as no molluscan bioevents were found to be associated with it. He placed the boundary between his Paparangi and Okiwa Groups at the top of the shellbed.

In a basin-wide study of foraminifera in the Wanganui area, Collen (1972) included several samples from the Wilkies Shellbed in both the Waitotara and Wanganui River sections. Paleoenvironmental interpretations from foraminiferal census of these samples compared favourably with the findings of Fleming's (1953) mollusc work, with calm, inner-shelf conditions prevailing during deposition of the shellbeds in both localities. This study also demonstrated that no foraminiferal bioevents were associated with the Wilkies Shellbed.

The first study to concentrate on the Wilkies Shellbed as a discrete unit was that of Christie (1973), who re-examined Flemings (1953) sections. He investigated the paleontology and sedimentology of the shellbed to establish its paleoevironmental depositional history.

Wilson (1993) in a paleomagnetic study of the Wanganui River section included a description of the Wilkies Shellbed, and sampled adjacent units for their magnetic polarity. Weak levels of remnant magnetisation and high levels of chemical remnant magnetisation gave mixed results. However, this study demonstrated proximity of the Wilkies Shellbed to the Gauss / Matayama transition (C2An.1n / C2r.2r) at 2.582 Ma (Lourens *et al.*, 1996).

The most recent study of the Wilkies Shellbed was by McIntyre & Kamp (1997), who in a study of the lower Wanganui River Pliocene strata, presented the stratigraphy between the Wilkies and Hautawa Shellbed, identifying 5 shellbeds and demonstrating that the succession was cyclothemic. Through sequence stratigraphic and textural analysis, that study revealed that the Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone comprised a complete cyclothem, and they gave a sequence stratigraphic interpretation of it.

Purpose of study:

The Wilkies Shellbed has been selected for detailed investigation because it represents a unique depositional setting over a large area in which *Crassostrea* flourished. No other shellbed in the Plio-Pleistocene part of Wanganui Basin contains *Crassostrea* in such abundance, which raises the question as to what balance of environmental conditions combined to allow the thick accumulations to form. Furthermore, the Wilkies Shellbed also shows lateral variability in thickness, facies and faunal content across the basin, allowing paleogeographic and environmental reconstructions of this part of the Wanganui Basin to be made for the late Pliocene.

Stratigraphic context:

The Wilkies Shellbed occurs in the middle of the Mangapanian Stage, and because of its distinctiveness, is a useful stratigraphic unit for correlation between sections of Mangapanian age. It crops out almost continuously as an abnormally thick, oyster-dominated coquina between the Parihauhau Road section in the east and Okiwa Trig near Waitotara in the west. Outside this area, identification of the Wilkies Shellbed within the Mangapanian succession is more difficult for two reasons. To the east of the Parihauhau Road section, the Wilkies Shellbed is very thin and has been located with confidence in this study in the Whangaehu River valley section at Mangamahu, where it is only a few centimetres thick, and lacks *Crassostrea* fossils. To the west of Okiwa Trig, identification of the shellbed is problematic because of poor exposure. It cannot be shown unequivocally that the shellbed cropping out at Wilkies Bluff is the same unit as the unit mapped inland to the east. This uncertainty was first alluded to by Beu (1969, p.646). Similar uncertainty exists for the thick *Crassostrea* shellbed cropping out in the Ohie and Ohieiti stream sections near Waitotara, described and collected by Fleming (1953) who nevertheless considered them to be the Wilkies Shellbed.

Because of its uniqueness throughout much of the basin, the Wilkies Shellbed is an obvious choice for a formal stratigraphic boundary. In the first formal subdivision of Pliocene strata in Wanganui Basin, Fleming (1953) designated the Wilkies Shellbed as the uppermost unit of the Paparangi Group, with the top of the shellbed marking the boundary between the Paparangi and Okiwa Groups. This designation remained until McIntyre & Kamp (1997) emended the stratigraphic extent of the Paparangi and Okiwa Groups, placing the base of the Okiwa Group at the base of the Wilkies Shellbed. This emendation was argued on the basis that the base of the Wilkies Shellbed was a more mappable horizon than its top, a feature common to most shellbeds in Wanganui Basin. In this study, the Paparangi / Okiwa Group boundary remains at the base of the Wilkies Shellbed, but these groups have been downgraded to subgroups within the Tangahoe Group (new, see Chapter 3). Fleming (1953) gave the Wilkies Shellbed formational status. McIntyre & Kamp (1997) downgraded the Wilkies Shellbed to a member of the Whauteihi Formation. This formation comprises the Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone Members. This study retains the usage of the Whauteihi Formation and the three constituent members.

No biostratigraphic datums have yet been associated with the Wilkies Shellbed, so correlation between sections is achieved by physical mapping and the distinctive *Crassostrea* content. However, other shellbeds in the Mangapanian succession also contain large numbers of *Crassostrea* specimens, including particularly the School Shellbed in Kauarapaoa and Wanganui valleys. This necessitates accurate stratigraphy of the sections in which the Wilkies Shellbed occurs to demonstrate accurate stratigraphic correlation.

The Te Rimu Sandstone problem.

The first basin-wide correlation of Pliocene and Pleistocene strata in Wanganui Basin (Feldmeyer *et al.*, 1943) correlated a sandstone unit at Te Rimu, near Parikino in the Wanganui River valley, with a thick sandstone unit that occupies a similar stratigraphic position in the Rangitikei River valley. This correlation was based on three factors: a) both units are sandstone, of similar texture and appearance; b) the two units are a similar stratigraphic distance below the Hautawa Shellbed, the most proximal, easily identifiable unit common to both localities; and c), both sandstone units occupy a position in the stratigraphy that was associated with the top of the underlying Mangaweka Mudstone (Enclosure 1). Feldmeyer *et al.* (1943) named this sandstone the "Basal Nukumaruan Sandstone", a name that was rejected by Fleming (1953) because of complications with the name of the Nukumaruan Stage. Fleming renamed the sandstone unit the Te Rimu Sandstone and placed it within the Mangapanian Stage, maintaining the correlation between the Wanganui and Rangitikei River valleys proposed by Feldmeyer *et al.* (1943). However, Fleming (1953, p.128) was not confident about mapping the unit west of Kauarapaoa valley. The proximity of the Te Rimu Sandstone above the Wilkies Shellbed probably influenced Fleming (1953) to place the Paparangi / Okiwa Group boundary at the *top* of the Wilkies Shellbed, rather than the more mappable and obvious base of the shellbed. This brought the group boundary stratigraphically closer to the Te Rimu Sandstone, and allowed extension of the Okiwa Group eastwards into the Turakina valley, beyond the eastern limit of the Wilkies Shellbed. Furthermore, Fleming (1953) completely ignored the Cable Siltstone (which separates the Wilkies Shellbed from the Te Rimu Sandstone), which meant that the Paparangi / Okiwa Group boundary occurred at either of two horizons in the Wanganui River section. This system remained until Ker (1973) described the Cable Siltstone, and relocated the base of the Okiwa Group at the base of the Te Rimu Sandstone. Naish & Kamp (1995) followed Fleming's (1953) correlations, and named the first sandstone above the Mangaweka Mudstone the Te Rimu Sandstone. Extending this study to include a sequence stratigraphic interpretation of the Rangitikei River succession showed that this sandstone was one 41 k.y. duration sequence beneath the Hautawa Shellbed (Naish & Kamp, 1997). Subsequent work in the Wanganui River section by McIntyre (1997) and Kamp & McIntyre (1998) showed that the type Te Rimu Sandstone was at least six 41 k.y. duration sequences stratigraphically below the Hautawa Shellbed, and was thus not the same (Te Rimu) sandstone unit as mapped in the Rangitikei River valley. Furthermore, substantial variations in thickness and bounding surfaces between the two sandstone units make correlation between them dubious. Recognition of this miscorrelation led to McIntyre & Kamp (1997) re-defining the base of the Okiwa Group at the base of the Wilkies Shellbed, a more mappable horizon. Subsequently, the sandstone immediately above the Mangaweka Mudstone in the Rangitikei River valley has been informally renamed the "Mangarere Sandstone" (Carter & Naish, 1998).

Age of the Wilkies Shellbed.

Park (1887) gave the shellbed at Wilkies Buff a lower Miocene age, although the basis for this age is not clear, and was probably arbitrary. In 1910, Park re-evaluated this age and placed his Waitotara Crags (which included the shellbed at Wilkies Bluff) in the Pliocene epoch, an age assignment accepted by subsequent workers (e.g. Laws, 1940). Fleming (1953) placed the shellbed in the middle of the Mangapanian Stage.

The first match of the Wilkies Shellbed to the Oxygen Isotope timescale was attempted by McIntyre & Kamp (1998) who correlated the Wilkies Shellbed in the Parikino section with Isotope Stage G8, giving it an age of about 2.75 Ma. New magnetostratigraphic and radiometric dates established for the succession in Wanganui valley and adjacent sections (Chapter 4) show that the Wilkies Shellbed lies 80 metres above the Gauss / Matayama (C2An.1n / C2r.2r) transition in the Wanganui River section at Parikino (Figure 6.1). The Gauss / Matuyama transition is located 20 m below the top of the Mangaweka Mudstone. This interval of strata correlates with the Gully Shellbed in the Wairangi section to the west of Wanganui River. The Gully Shellbed is two shellbeds stratigraphically beneath the Wilkies Shellbed. Assuming a 41 k.y. periodicity of sequence formation, an age of 2.50 Ma results for the Wilkies Shellbed. The discovery of a pumiceous tephra immediately above the Otere Shellbed in the Kauarapaoa valley has provided an opportunity for radiometric age determination. A U-Th/He age of 2.57 ± 0.04 Ma has been obtained for the Otere Tephra. For the purposes of this study, the Wilkies Shellbed is given an age of 2.50 Ma, based on the magnetostratigraphic ages shown above, supported by the U/Th-He age on the Otere Tephra.

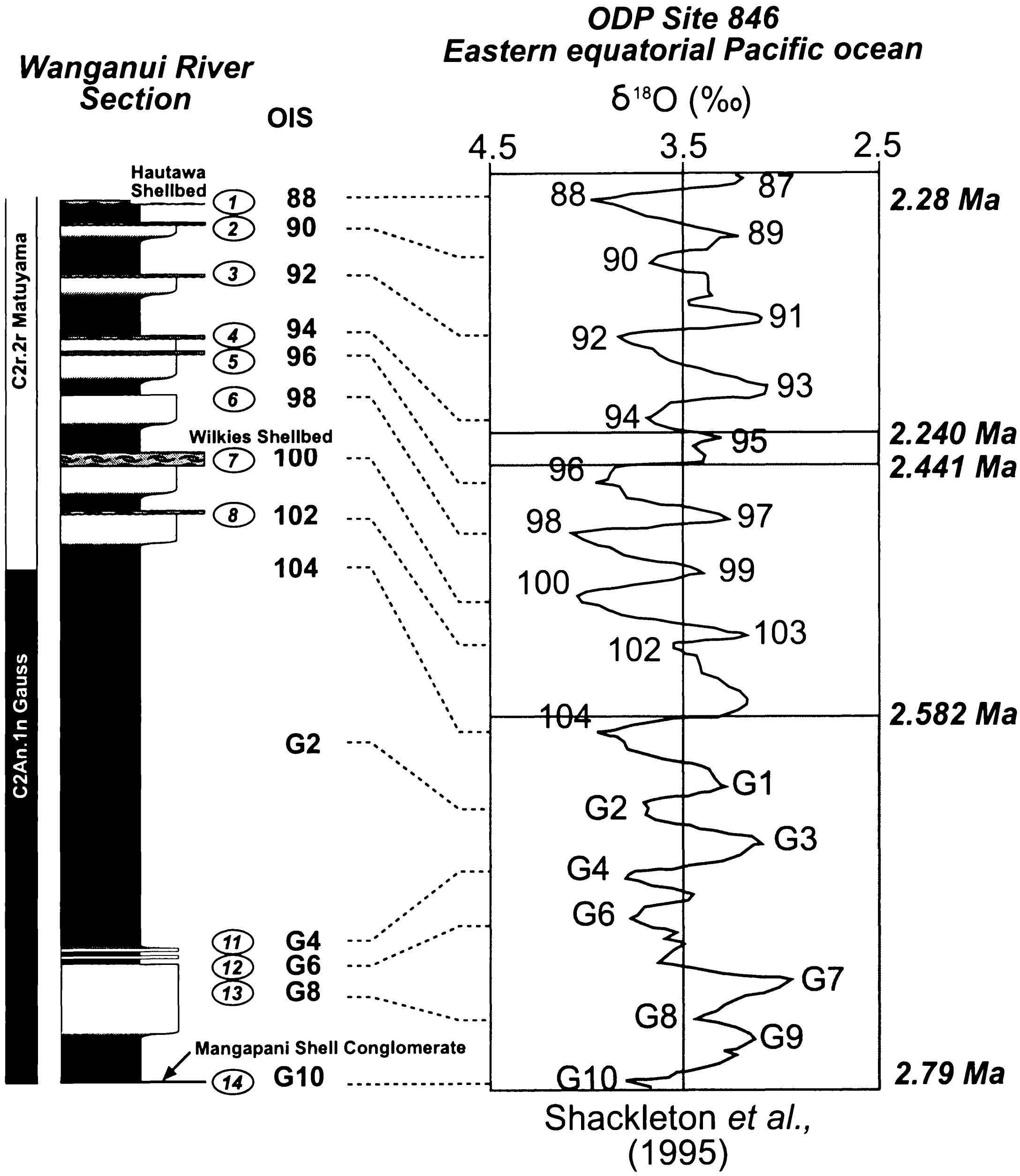


Figure 6.1: Correlation of Mangapanian Stage strata in Wanganui River valley with Oxygen Isotope Curve for ODP site 846. This interpretation shows a match between the Wilkies Shellbed and OIS 100, giving an age of 2.50 Ma.

Section Descriptions: Facies content.

The following descriptions are supplementary to those given for the same units in Chapter 3 (Lithostratigraphy). Here, sequences are described in terms of their constituent facies, which are defined in Table 6.1. This method of classifying the geology in terms of their constituent facies is necessary for the investigation of facies trends, which is investigated in further detail in a later section of this chapter.

Table 6.1: Facies groups and codes for Whauteihi Formation.

Groups	Lithofacies code	Description	Typical example	Depositional environment
Siltstone Group	Z_1	Barren to sparsely fossiliferous, massive bioturbated siltstone. *Atrina* often present.	Cable Zst, Parikino	Mid-shelf
	Z_2	Barren to sparsely fossiliferous, massive, bioturbated fine sandy siltstone	Cable Zst, Mangamahu	Inner–mid shelf
Sandstone Group	S_1	Barren to sparsely fossiliferous, massive, bioturbated, silty fine sandstone	Te Rimu Sst, Parihauhau	Inner-shelf
	S_2	Barren to moderately fossiliferous, bioturbated, massive fine micaceous sandstone	Makokako Sst. Kauarapaoa	Shoreface
	S_4	Barren to moderately fossiliferous, bioturbated, decimetre scale horizontally bedded fine sandstone	Te Rimu Sst, Parikino, Wanganui Riv.	Inner-shelf
	S_8	Slighty bedded, fossiliferous silty sandstone with common *Divaricella, Amalda.*	Lenses within Wilkies, Parikino	Inner-shelf, channel.
Shellbed Group	Cz_1	Clumps and bands of in / near situ shells (*Pratulum, Atrina, Chlamys*) within bioturbated massive siltstone. Matrix dominated	Wilkies Shellbed, Mangamahu	Outermost inner-shelf
	Cz_4	Closely packed shells within sandy siltstone. *Crassostrea* dominant, with common *Chlamys* and brachipods	Wilkies Shellbed, Wanganui Riv.	Inner-shelf
	Cs_1	Closely packed shells (typically bivalves – *Eumarcia, Dosinia, Gari, Divaricella, Pteromyrtea*) within bioturbated silty sandstone and sandstone	Base Wilkies Shellbed, Kauarapaoa	Inner-shelf

While all of the individual units described below (Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone) are members of the Whauteihi Formation, it is inconvenient to include the term "Member" each time one is referred to, as it is overly repetitious.

Whangaehu River valley section (Mangamahu): (Fig 6.2a)

In the Whangaehu River valley, the Wilkies Shellbed crops out in a road cutting about 3.5 kms north of Mangamahu township (site 56, S22/134541). There it is a very weakly developed shell accumulation, 1 m thick, at the base of a 14 m thick siltstone (Cable Siltstone), with a few highly weathered and unidentified bivalves (possibly *Pratulum*) dominating the faunal assemblage, along with rare *Chlamys gemmulata*, *Patro* and *Atrina* (facies Cs_1, grading upwards into facies Cz_1). No specimens of *Crassostrea* occur in the Wilkies Shellbed in this section. Correlation was achieved by stratigraphic positioning of the shellbed in relation to the Hautawa Shellbed and other shellbeds in the Okiwa Subgroup succession. The shellbed is conformable with the underlying Makokako Sandstone. At this roadside section, a normal fault displaces the shellbed below road-level, but a throw of 8 m can be estimated from a prominent concretionary horizon that crops out 8 m above the shellbed. Above the Wilkies Shellbed, the Cable Siltstone (facies Z_1, 14 m thick) crops out on the roadside to the south of the Wilkies Shellbed, and has a relatively high sand content (30–45%) coarsening gradually upsection into the Te Rimu Sandstone. In this section the Te Rimu Sandstone is a light brown sandstone of facies S_2, some 8 m thick, unconformably underlying the Mangamahu Shellbed.

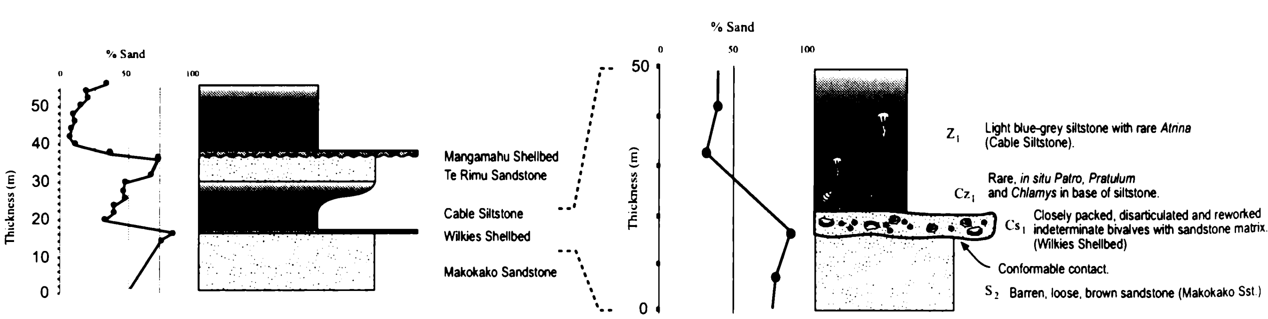


Figure 6.2a: Whauteihi Formation, Whangaehu River valley (left) and facies detail of Wilkies Shellbed at this locality (right).

Parihauhau Road section: (Fig 6.2b)

The Wilkies Shellbed crops out on a roadcut on Parihauhau Road near Parihauhau School (site 73, S21/031616), as a 12 m thick shellbed dominated by *in situ Crassostrea* within a massive siltstone matrix (facies Cz_4). It conformably overlies Paparangi Subgroup siltstone with little or no relief on the gradational contact between the two units. The shellbed has the same facies throughout, with no bedding features or grainsize variations evident. The shellbed is best exposed on bluffs high above Parihauhau Road, as the roadside outcrop is not in place, and appears to have slumped downslope from the bluffs. The faunal assemblage is almost completely dominated by *Crassostrea* and *Chlamys gemmulata,* with rare *Amalda.* Above the Wilkies Shellbed, the Cable Siltstone is a massive siltstone facies (Z_1) 51 m thick, and is conformably overlain by the Te Rimu Sandstone (facies S_2, 10 m thick). The upper contact of the Te Rimu Sandstone is at S21/033608, where unnamed siltstone of the Whakaihuwaka Formation unconformably overlies the Te Rimu Sandstone, with burrows extending downwards into the sandstone from the sharp contact.

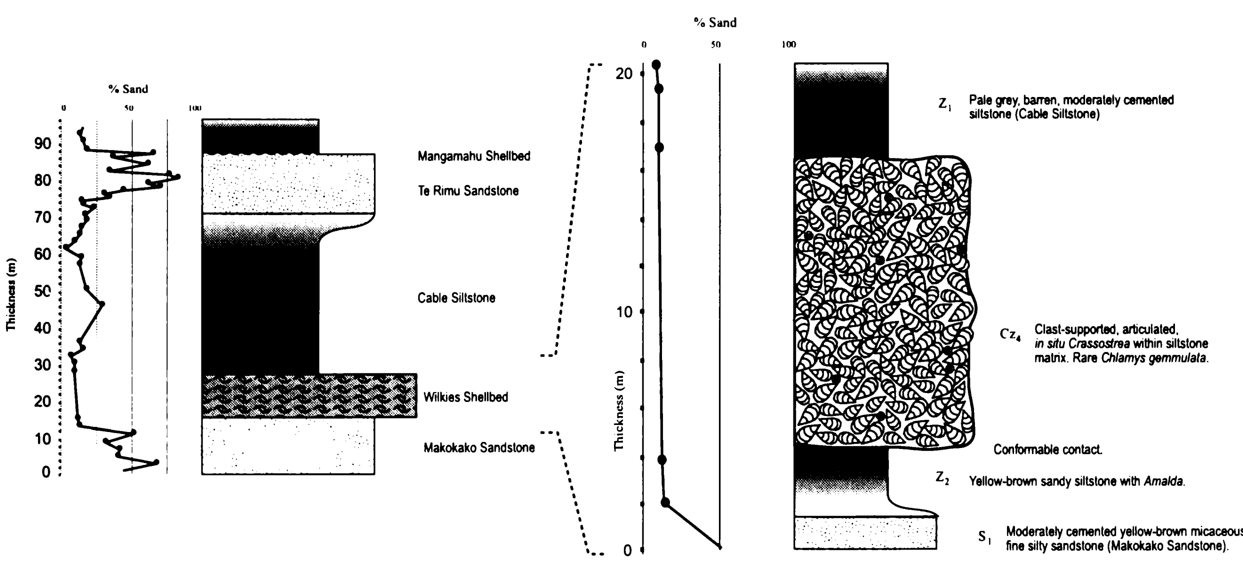


Figure 6.2b: Whauteihi Formation, Parihauhau Road section (left) and facies detail of Wilkies Shellbed at this locality (right).

Wanganui River section (Parikino): (Fig 6.2c)

The spectacular exposure of the Wilkies Shellbed beside the Wanganui River Road at Te Rimu (site 38, S22/954572) is the most widely known and easily accessible locality of the shellbed within Wanganui Basin. As described by McIntyre & Kamp (1998), the Wilkies Shellbed is a crudely horizontally bedded unit with a fine sandstone matrix. The shellbed conformably overlies the Makokako Sandstone. A prominent concretionary horizon, 0.5 m thick, marks the lower contact. The maximum thickness of the Wilkies Shellbed here is 15 m, with a relief of up to 10 m on the upper surface. Packed molluscs within a sandstone matrix are common in the lower 3 m, with 0.2 m thick alternating beds of *Crassostrea* and *Chlamys* and fine sandstone. The matrix in the upper part of the shellbed fines upwards to siltstone, with abundant *in-situ Crassostrea* and *Chlamys,* and rare *Ostrea, Purpurocardia* and *Neothyris* (facies Cz_4). Thick sandstone lenses up to several metres in width throughout the shellbed contain a different faunal assemblage from that of the main shellbed, with thin horizons and pockets of *Maoricolpus, Amalda, Divaricella, Zenatia* and *Cyclomactra* (facies Z_8). These sandstone lenses are dome-shaped, and in some places, horizons of *Crassostrea* extend a few decimetres into the lens. The Cable Siltstone conformably overlies the Wilkies Shellbed, and reaches a maximum thickness of 28 m (facies Z_1). Specimens of *Atrina* are common throughout the Cable Siltstone, with rare specimens of *Ostrea* and *Chlamys* in the upper part. The Cable Siltstone coarsens upsection into the Te Rimu Sandstone, which is a 20 m thick, slightly horizontally bedded (0.1–1 m beds) silty sandstone, belonging to facies S_4. Thin shell lenses are rare in the upper part of the Te Rimu Sandstone, with one lens at S22/943574 containing a diverse shallow-water assemblage including *Gari, Divaricella* and *Pteromyrtea* (GS 4214; Fleming, 1953).

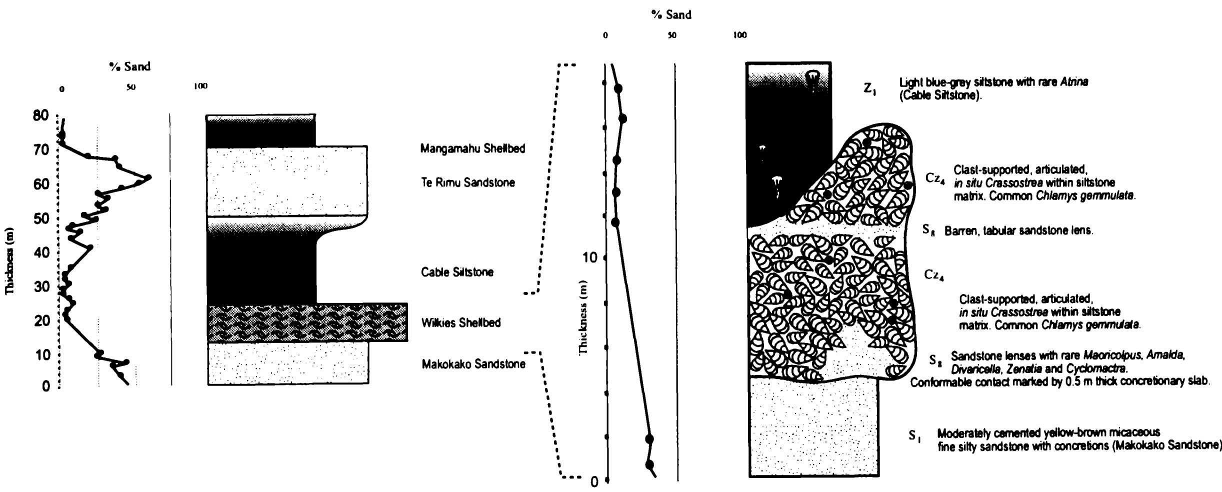


Figure 6.2c: Whauteihi Formation, Wanganui River valley section (left) and facies detail of Wilkies Shellbed at this locality (right).

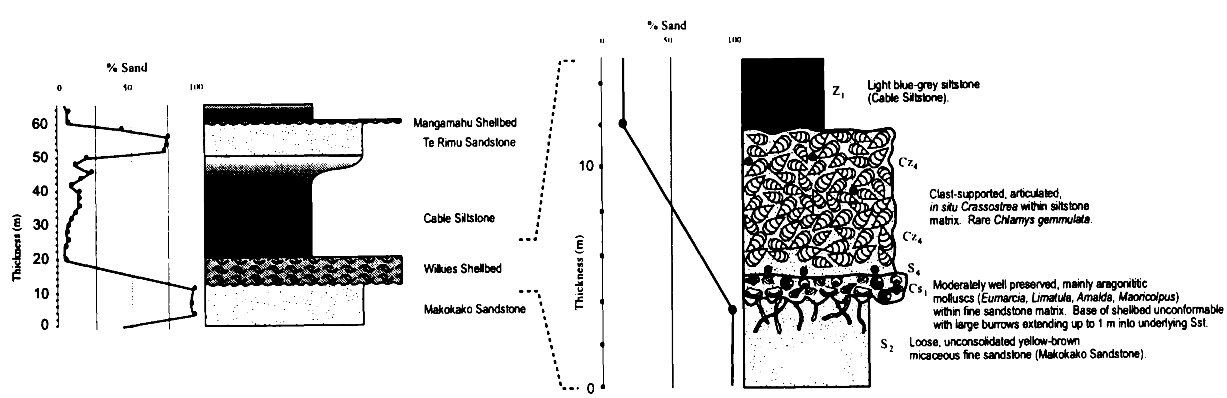


Figure 6.2d: Whauteihi Formation, Kauarapaoa valley section (left) and facies detail of Wilkies Shellbed at this locality (right).

Kauarapaoa valley section: (Fig 6.2d)

The Wilkies Shellbed crops out near-continuously throughout the Kauarapaoa valley, where it forms prominent bluffs on steep hillsides above the Kauarapaoa Stream. The shellbed crops out near a farm track at site 23 (R22/902594; site GS 4208, Fleming, 1953) on the roadside at R22/902594 and below the road at site 24 (R22/900581), where exposure of the lower part of the Wilkies Shellbed is probably the best in the entire basin. The thickness of the shellbed is uniformly 8 m throughout the valley, with the exception of site 25, where the Wilkies Shellbed seems to be absent. The faunal assemblage within the Wilkies Shellbed is much more diverse in the Kauarapaoa valley than in the Wanganui valley, with two parts to the shellbed. The lower part is a sandy coquina facies (Cs_1), 0.5 m thick, unconformable with up to 1 m relief upon the underlying Makokako Sandstone. This sharp contact between the moderately cemented shellbed and the loose sandstone beneath forms an overhanging ledge, which is highly visible throughout much of the valley. Large *Ophiomorpha* burrows extend up to 1.5 m downwards into the Makokako Sandstone from the base of the shellbed, and at site 24, the loose Makokako Sandstone has eroded away to expose the burrows, which are infilled with silty sandstone containing fragments of aragonitic shell material. The faunal content within the lower 0.5 m of the Wilkies Shellbed is dominated by bivalves (*Pteromyrtea, Limatula, Ostrea, Eumarica*) with gastropods (*Maoricolpus, Amalda*) also common. Most bivalves are disarticulated, lying horizontally within the silty sandstone matrix. In undercut surfaces, disarticulated specimens of *Eumarcia plana* are dominant. Above the lower part of the shellbed, there is a sparsely fossiliferous interval of 0.1 m, which contains a few *Chlamys* specimens and Bryozoans. Above this unit is the main part of the shellbed, 7.5 m thick, which is comprised of abundant *in-situ Crassostrea* and *Chlamys* within a sandy siltstone matrix, the same facies (Cz_4) as the Wilkies Shellbed in the Wanganui River section. Conformably overlying the Wilkies Shellbed, the Cable Siltstone reaches its maximum thickness of 31 m, and is a typical blue-grey, barren, massive mudstone (facies Z_1). The Cable Siltstone coarsens rapidly over 2 m into the Te Rimu Sandstone, which is a 10 m thick, barren, massive silty sandstone of facies S_2. The upper 0.2 m at the top of the Te Rimu Sandstone is flaser bedded. It is punctuated by burrows extending downwards from the Mangamahu Shellbed, which rests unconformably upon the Te Rimu Sandstone.

Wairangi Station: (Fig 6.2e)

The Wilkies Shellbed crops out on, and forms the watershed between, the Kauarapaoa and Mangaiti valleys, between the Kauarapaoa and Wairangi sections. Between these two sections, the shellbed thickens westwards, from 8 m in the Kauarapaoa section to 10 m at Wairangi. There, it crops out in the hillside above Wairangi Station, near the abandoned northern part of Tokomaru East Road. The Wilkies Shellbed is well exposed at several localities, particularly at R21/833622 (GS 4211; Fleming, 1953), and site 21 at R21/841617 (GS 4213; Fleming, 1953). Access to both of these localities is difficult, as regenerating bush conceals both sites. At site 21, the Wilkies Shellbed is 10 m thick, and lies unconformably above the Makokako Sandstone. Here, the shellbed has two main parts, both similar to their correlatives in the Kauarapaoa valley. The lower part (1 m thick) contains a diverse, reworked faunal assemblage, with common *Crepidula, Gari*, *Chlamys, Anomia* and *Sigapatella* (facies Cs_1). No bedding is obvious in this part of the shellbed, but most specimens are oriented horizontally within the sandstone matrix. This unit is conformably overlain by the *Crassostrea*-dominated facies (Cz_4) common to the Wilkies Shellbed in correlative sections. Here it is 4 mthick, and comprises *in-situ Crassostrea* and *Chlamys gemmulata* within a sandy siltstone matrix. At site 21, this unit is overlain by a silty sandstone unit, 4 m thick, which contains rare *Divaricella, Purpurocardia, Maoricolpus* and *Crepidula,* and is similar in appearance (facies S_8) to the sandstone lenses within the Wilkies Shellbed at Te Rimu in the Wanganui River section. Above this unit is a further 1 m of *in situ Crassostrea* within siltstone, accompanied by rare specimens of *Neothyris.* The Cable Siltstone and Te Rimu Sandstone are masked by scrub in this section.

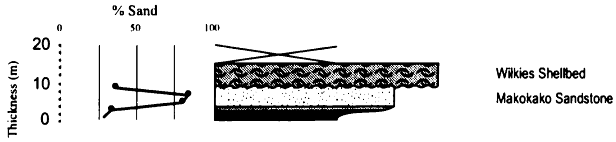


Figure 6.2e: Whauteihi Formation, Wairangi section. A detailed facies log is not provided for the shellbed at this locality, as it is not fully exposed.

Paparangi (Rangitatau East Rd): (Fig 6.2f)

The Wilkies Shellbed is well exposed on the roadside about 2 km north of Paparangi Peak, at site 14 (R21/784637; GS 4209, Fleming, 1953). This locality is within the Nukumaru Fault Zone, with a fault trace cutting through the Wilkies Shellbed, displacing it with normal throw of at least 12 m to the south. The shellbed is thinner here than it is in the Wanganui and Kauarapaoa valleys, with a total thickness of 3.5 m made up of two parts. The lower part of the shellbed is 2 m thick, and contains a diverse assemblage of near *situ* molluscs, with common *Ostrea, Phialopecten, Patro, Purpurocardia, Crepidula* and *Neothyris* (facies Cs_1). This lower shellbed unconformably overlies the Makokako Sandstone, with up to 0.5 m of vertical relief over 2 m horizontally on the contact. The lower shellbed grades abruptly into the upper *Crassostrea*-rich part of the shellbed, which has thinned to 1.5 m in this section, and is comprised of *in situ Crassostrea* and *Chlamys* specimens within siltstone matrix (facies Cz_4), which is common to the shellbed in the central parts of the Wanganui Basin. Above the Wilkies Shellbed, the Cable Siltstone (facies Z_2) is only 2 m thick, and is abruptly truncated by the unconformity at the base of the Mangamahu Shellbed. The Te Rimu Sandstone is not present in this section, presumably missing in the unconformity at the base of the Mangamahu Shellbed. Fleming (1953) tentatively correlated the sandstone immediately above the Mangamahu Shellbed with the Te Rimu Sandstone and published a faunal list for it (GS 4210). However, this study has established that this sandstone is not the Te Rimu Sandstone, but an unnamed sandstone bed separating the upper and lower parts of the Mangamahu Shellbed.

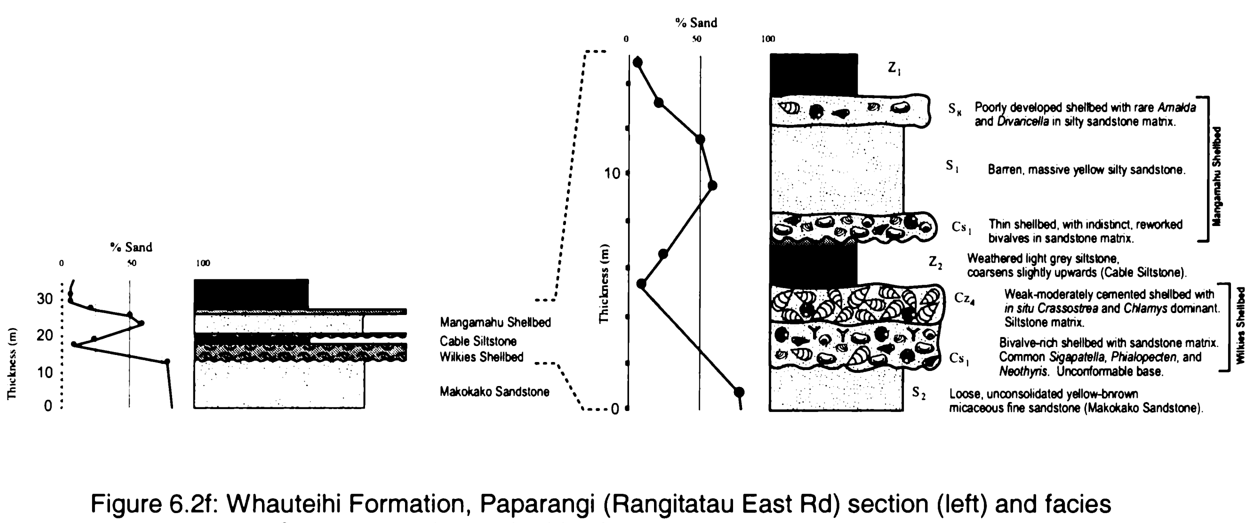


Figure 6.2f: Whauteihi Formation, Paparangi (Rangitatau East Rd) section (left) and facies detail of Wilkies Shellbed at this locality (right).

Okiwa Trig (Rangitatau West Road) (Fig 6.2g)

Fleming (1953) described the Wilkies Shellbed below Te Rama Trig (GS 4226), a locality not found during fieldwork for this study. However, the Wilkies Shellbed is well exposed in the large gully on the northern slope of Okiwa Trig (site 8, R22/714598), where the entire Okiwa Group and much of the Paparangi Group occur in a 250 m high gully escarpment. The Wilkies Shellbed in this section is 3 m thick, unconformably overlying poorly cemented, bedded (0.1-0.5 m) Makokako Sandstone. The lower part of the Wilkies Shellbed contains typical facies Cs_1, - a reworked fossil assemblage, with common *Barnea, Ostrea, Tawera, Amalda, Maoricolpus* and *Neothyris* within the sandstone matrix. All bivalves are disarticulated, although *Neothyris* specimens are articulated. The upper 1.5 m thick part of the shellbed is the *Crassostrea* facies (Cz_4) common to other sections. Unconformably superimposed directly on the upper *Crassostrea* part of the Wilkies Shellbed is the Mangamahu Shellbed. A previously unrecognized fault within the Nukumaru Fault Zone cuts though the section at this locality, obscuring details of the upper part of the Mangamahu Shellbed and the siltstone above it.

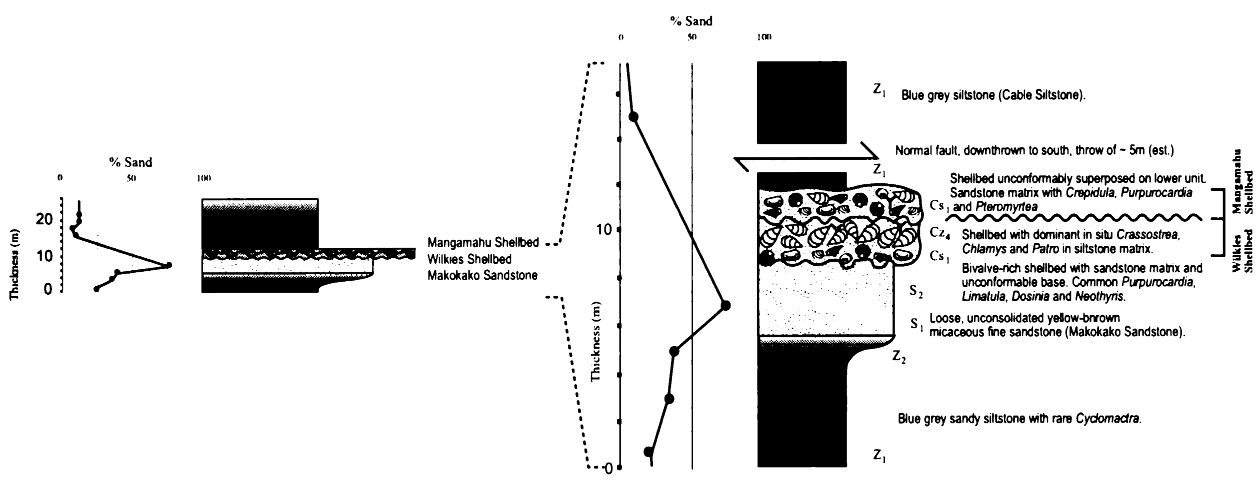


Figure 6.2g: Whauteihi Formation, Okiwa Trig (Rangitatau West Rd) section (left) and facies detail of Wilkies Shellbed at this locality (right).

Ohie Stream, Ohie Gorge, Wilkies Bluff:

Each of these sections was visited during fieldwork for this study. It is concluded that there is considerable doubt as to whether the *Crassostrea*-rich shellbed these localities is in fact the Wilkies Shellbed. All of these sites are isolated outcrops of shellbed only, offering no other stratigraphic control. The progressive thinning of the Wilkies Shellbed from east to west, and the incision of the Mangamahu Shellbed into the Te Rimu Sandstone, Cable Siltstone and eventually into the Wilkies Shellbed further west at Okiwa, suggests that the Wilkies Shellbed might not extend much further west than Okiwa Trig, having been truncated by the angular unconformity at the base of the Mangamahu Shellbed. Furthermore, other correlatives for the shellbed at Ohie Stream, Ohie Gorge, and Wilkies Bluff exist. In particular, either the Gully Shellbed or Mangamahu Shellbed, both of which crop out in the Okiwa escarpment, could be the shellbed at Wilkies Bluff. The view taken in this study is that the shellbed/s cropping out in the Ohie Stream, Ohie Gorge, and Wilkies Bluff sections are probably not the Wilkies Shellbed, and thus they are not described here. Because the shellbed at Wilkies Bluff was designated as the type section for the Wilkies Shellbed, it is proposed that this locality should be abandoned, and the type locality reassigned to one of the inland sections where identification of the Wilkies Shellbed is definitive. The most logical site for quality of exposure, access and stratigraphic control is on the Wanganui River valley roadside at Te Rimu. Accordingly, this locality is proposed as the new type section for the Wilkies Shellbed.

Molluscan paleoecology and depositional depth analysis.

The Wilkies Shellbed with its concentration of *Crassostrea* represents a unique faunal content and setting in Wanganui Basin. *Crassostrea* can dominate in the upper parts of other shellbeds within the basin, but these occurrences are normally less than 1 m in thickness. The only exception is the School Shellbed on the Kauarapaoa / Mangaiti watershed at R22/893574, where a *Crassostrea* layer is ~ 11 m thick. The School Shellbed is about 0.2 m.y. younger than the Wilkies Shellbed, and provides a useful comparison that helps in reading the depositional paleoenvironment of *Crassostrea* accumulations.

Modern *Crassostrea* reef communities exist in predominately brackish, estuarine environments, where food is abundant and predation from marine organisms (e.g. gastropods, starfish, sponges) is low (Wells, 1961). The extant species of the genus include *Crassostrea gigas* (Pacfic Oyster) and *Crassostrea virginica,* both of which inhabit estuarine settings, with *Crassostrea gigas* found in waters with salinities of between 25-35 ‰, preferring a level of 30 ‰ compared with the normal 35 ‰ for sea water in fully marine conditions (Pauley *et al.,* 1988). *Crassostrea virginica* (Eastern American Oyster) inhabits slightly less saline waters between 10-30 ‰, preferring salinities of around 28 ‰ (Cake, 1983).

Nelson *et al.* (1983) in an isotopic study of Oligocene and Early Miocene giant oysters from the Orahiri Limestone in the Te Kuiti Group (Northen Wanganui Basin) cropping out in similar 'reef' fashion to the Wilkies Shellbed demonstrated that they lived in fully marine conditions, at depths of around 25-50 metres. However, the identification of these Oligiocene oysters is somewhat uncertain. They could be cf. *Crenostrea wuellerstorfi*, cf. *Flemingostrea wollastoni* or *Flemingostrea nelsoniana.* The cautious identification of Nelson *et al.,* (1983) regarding the Te Kuiti Group giant oysters, suggested their closest similarity to the genus *Flemingostrea,* a close relative of *Crassostrea* in the family Ostridae. Although the identity of the Te Kuiti Group giant oysters is uncertain, the near-monospecific, clast-supported, thickly bedded (up to 9 m) biostromes in which they occur are remarkably similar to the *Crassostrea* biostromes in the Wilkies Shellbed. Comparison between the Orahiri Limestone and Wilkies Shellbed is illustrated in figure 6.3, which shows the similarity in size and density of Ostridae in the two units. One point of note is that *Crassostrea* specimens in the Wilkies Shellbed are mainly *in situ*, oriented vertically within the siltstone matrix. This implies a depositional environment slightly less influenced by currents than that of the Orahiri Limestone, where the near *situ* oysters are still articulated, but more randomly oriented, indicating greater water movement. Laws (1940, p. 41) suggested that the depositional environment for Mangapanian *Crassostrea ingens* in Wanganui Basin was analogous to that of *Ostrea chilensis* in Foveaux Strait, a comparison also favoured by Nelson *et al.* (1983) for the oyster-dominant part of the Orahiri Limestone. Fleming (1953) noted that the Wilkies Shellbed lacked the restricted, intertidal fauna normally found in assemblages containing other species of *Crassostrea* (i.e. *C. gigas* and *C. virginica*) and inferred a contemporary depth of 10 to 45 m, in an offshore setting influenced by currents. Nelson *et al.* (1983) interpreted the depth of oyster accumulation in the Orahiri Limestone at between 25-50 m, in a fully marine, tide-swept strait.

Christie (1973) also noted the lack of estuarine taxa in the Wilkies Shellbed, but despite this placed considerable emphasis on the ecology of modern *Crassostrea*, and favoured a restricted depositional environment of shallow estuarine lagoons and semi-enclosed bays joined by tidal channels to the sea.

Collections made in this study show that the fauna dominating both the lower and upper parts of the Wilkies Shellbed between Okiwa Trig and Parihauhau Road sections is overwhelmingly marine, with the dominant taxa (other than *Crassostrea*) being *Chlamys gemmulata, Ostrea chilensis* and brachiopods, all of which occur mainly in high-energy, open coastal settings of moderate to high salinity (Morton & Miller, 1968; Powell, 1979; Beu & Maxwell, 1990). Two other common species occurring in the Wilkies Shellbed are *Purpurocardia purpurata* and *Atrina zelandica*, both of which inhabit a wide range of environments from tidal channels to the open coast, providing little definitive evidence for paleoecology or bathymetry of the shellbed (Powell, 1979). While some species of *Amalda* commonly occur in estuarine conditions, the extinct species *Amalda oraria* is the most common within the Wilkies Shellbed, and is a possible ancestor of *A. mucronata*, which is common on the modern inner-mid shelf, providing further evidence for an open, unrestricted marine environment (Beu & Maxwell, 1990). The two possibly estuarine fossil specimens found were one specimen of *Xenostrobus* sp. from Okiwa Trig, and a single valve of *Lutraria solida* from Kauarapaoa valley, both specimens collected from the lower part of the Wilkies Shellbed. However, these isolated specimens were not articulated or *in situ,* meaning that little emphasis can be placed on their occurrence. Notably, estuarine fossils found elsewhere in the Wanganui Basin Mangapanian succession are absent from the Wilkies Shellbed, with typically restricted taxa such as *Nucula, Cyclomactra, Austrovenus. Micrelenchus, Zeacumantus, Cominella* and *Xymene* not occurring in the shellbed at any of the localities described above.

While there may be a subtle estuarine influence on the fauna in the lower part of the Wilkies Shellbed, the upper part has more affinities with a nearshore, marine setting of moderate to high salinity, as indicated by the abundance of *Chlamys gemmulata* and brachiopods (mainly *Neothyris*). Clearly, the large thickness of *Crassostrea ingens* in the upper part of the shellbed indicates that the food supply to the "reef" was sufficient to enable the growth of the oysters to keep pace with the rate of sedimentation, but not enough to enable the serious establishment of another species that would in turn compete for nutrients. This demonstrates that the Wilkies Shellbed was a large biostrome, in which *Crassostrea* flourished, with a low enough level of turbidity and rate of sediment accumulation to enable new spat to become established on mature shells and continue reef building at a rate greater than the aggradation of the terrigenous material comprising the matrix. Thus the *Crassostrea* population was able to maintain optimum conditions for its own survival by growing fast enough to avoid being buried by sediment, and also possibly maintaining a fairly constant bathymetry.

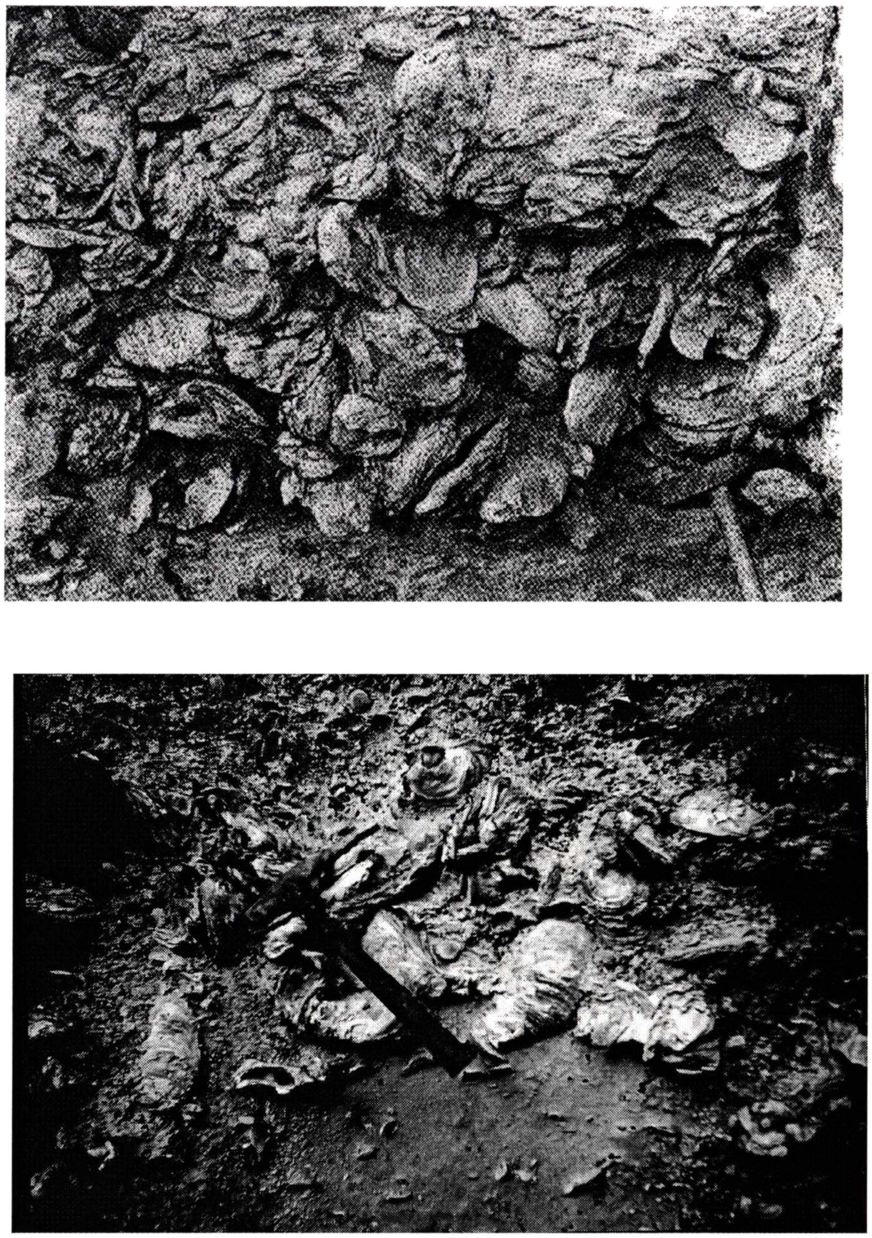


Figure 6.3: Comparison of Giant Oyster biostromes: Upper - within Orahiri Limestone (Nelson *et al.,* 1983); Lower - near base of Wilkies Shellbed, Parikino, Wanganui River valley.

Facies Trends.

All of the units comprising the Whauteihi Formation can be classified into nine distinct facies, within three associations (siltstone, sandstone, and shellbed). The facies scheme used to classify the strata in this succession is summarised in Table 6.1. Generally, the vertical succession of facies associations in each section is shellbed to siltstone to sandstone, in ascending stratigraphic order. However, subtleties in facies differences between sections reveal several trends, which assist in determining aspects of the formation's depositional history. The Wilkies Shellbed has three shellbed facies, two of which have a siltstone matrix (Cz_1 and Cz_4), and one with a sandstone matrix (Cs_1). The dominant facies and the one that characterises the Wilkies Shellbed is facies Cz_4, followed by facies Cs_1, with the poorly condensed and fossiliferous facies Cz_1 representing the Wilkies Shellbed in only one section. In addition, one sandstone facies (S_8) is unique to the Wilkies Shellbed. Two siltstone facies comprise the Cable Siltstone, and reflect varying amounts of sand content within the siltstone. Three sandstone facies have been identified within the Te Rimu Sandstone, S_1 being a silty sandstone, S_2 a poorly cemented, loose, fine sandstone, and S_4 being sandstone of variable grainsize with decimetre-scale horizontal bedding.

The Wilkies Shellbed is thickest in the Parihauhau and Wanganui River sections, and thins both eastwards and westwards from these areas. The thinning from ~ 10 m at Parihauhau to < 1 m at Mangamahu in the Whangaehu River section can be attributed to the decrease in abundance of *Crassostrea* in the shellbed. Abundance ultimately reaches zero somewhere between the Parihauhau and Whangaehu River sections. To the west, the angular unconformity at the base of the Mangamahu Shellbed truncates the Whauteihi Formation and ultimately the Wilkies Shellbed itself. In the western sections of the basin, the shellbed thins from 10 m at Wairangi to 3.5 m at Paparangi, with this unconformity only influencing the shellbeds thickness at Okiwa Trig. However, the facies that comprise the Wilkies Shellbed also display lateral trends, all of which point to a westwards-shoaling profile.

Starting in the east, at the Whangaehu River valley (Mangamahu) section, the Wilkies Shellbed is represented by two facies. The lower part (Cs_1) contains unidentified, poorly preserved bivalves, possibly *Pratulum*. The inference here for the depth of deposition is an inner-shelf environment at a depth sufficient to have not been reworked substantially by waves and currents. Overlying this, the weakly defined shellbed in the base of the siltstone was probably deposited in deeper water, as indicated by the finer grained siltstone matrix. Notably, the *Crassostrea* facies is absent within the shellbed at this locality. The facies at this locality have no immediately adjacent lateral equivalent. This means that conditions of deposition here were very different from those in sections to the west.

The Parihauhau and Wanganui River valley sections are dominated by one carbonate facies, Cz_4, which was probably deposited in water depths both deep and quiet enough to allow the *Crassostrea* 'reef' to establish and grow without being reworked. The abnormal thickness of the Wilkies Shellbed in these sections means that extra accommodation and/or time was available for the shellbed to develop. Conversely, the sandstone lenses (facies S_8) within the shellbed contrast with the siltstone matrix of the shellbed, and contain a shallow-water faunal assemblage. These lenses are interpreted as shelf channels through which sands were transported from shallower-water depths on to the shelf, bypassing the *Crassostrea* biostrome. Shallow water molluscs such as *Divaricella* and *Cyclomactra* within the lenses support this interpretation, presumably having been entrained with the nearshore sands as they were transported basinward through the channel. Further evidence of these sandstone lenses being channels is displayed by the horizons of *Crassostrea* in the lower lens at site 38. *Crassostrea* horizons onlap and sometimes extend a few decimeters into the sandstone, indicating that at times the 'reef' grew over the channel, but could not become fully established due to the high sediment load and turbidity. Eventually, the movement of sand through the channel ceased or the channel migrated elsewhere, allowing *Crassostrea* to completely colonise the upper surface of the channel. Another lens near the top of the shellbed at this site is much wider, but is inaccessible, and only the upper and lower surfaces are revealed. It is also interpreted as a channel, through which sand was reworked basinward. This interpretation is also applied to similar facies in the Wilkies Shellbed at Wairangi, where a 4 m thick sandstone lens occurs within the *Crassostrea* facies (Cz_4).

In the Kauaraopaoa valley section, the Wilkies Shellbed has a different character. High-energy conditions are indicated by the sandstone matrix of the shellbed (Cs_1) at its base. This lower shellbed thickens from 0.5 m in the Kauarapaoa valley to 1 m at Wairangi, to 2 m at Paparangi and 1.5 m at Okiwa Trig. This lower facies is associated with an unconformable base to the shellbed, marked by erosional scours in the top of the underlying Makokako Sandstone. Conversely, the upper *Crassostrea* "reef" thins to the west, thinning from 8 m thick at Kauarapaoa, 5 m at Wairangi, and 1.5 m at both Paparangi and Okiwa Trig. At Okiwa Trig however, the Mangamahu Shellbed truncates the Wilkies Shellbed.

Above the shellbed facies, the Cable Siltstone and Te Rimu Sandstone also display lateral facies and geometric variations. The Cable Siltstone reaches maximum thickness (51 m) in the Parihauhau Road section, thinning eastwards to 14 m at Mangamahu, and thinning westwards to ~ 30 m in the Wanganui River and Kauarapaoa valley sections. To the west of Kauarapaoa valley, the Cable Siltstone is not complete, because of the unconformity at its upper contact. Thus, the depocentre of the Cable Siltstone was located in the vicinity of Parihauhau, and deposition took place in shallower water westwards. The relative thinness of the Cable Siltstone at Mangamahu is interpreted as the result of stratigraphic condensation in an offshore position relative to the other sections in which this sequence occurs. The Cable Siltstone is remarkably uniform in texture and lacks bedding features.

The Te Rimu Sandstone is comprised of coarser, higher-energy and probably shallower-water facies than the Cable Siltstone, probably indicating a reduction in depth of deposition. Compared with other Mangapanian sandstone units however, the Te Rimu Sandstone has a relatively high siltstone content. It exceeds 80 % sand only at the type section in the Wanganui River valley. This is possibly due partly to the occurrence of an unconformity overlying the sandstone at many localities. There may have been erosional truncation of a coarser upper part of the sandstone unit at several localities.

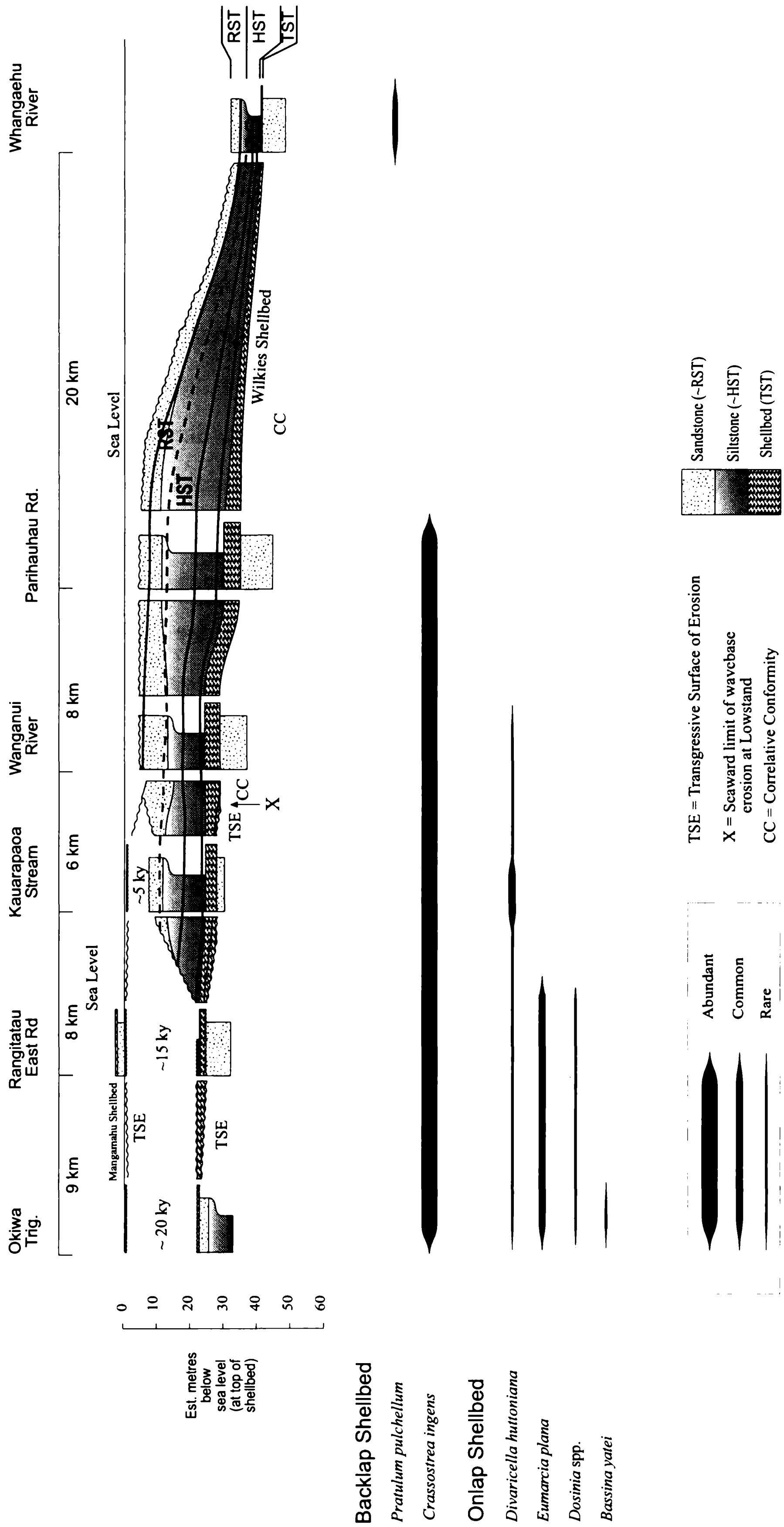


Figure 6.4: Cross-shelf profile of Whauteihi Formation, showing extent of main facies groups, distribution of ecologically useful molluscs, and sequence stratigraphic interpretation.

The depositional setting fitting most closely with the facies interpretation of the Whauteihi Formation between Okiwa and Parihauhau is an eastwards-deepening shelf setting (Figure 6.4). To the east of Parihauhau, the bathymetry increased, resulting in different facies and thicknesses of units in the vicinity of Mangamahu from those further westward. The westwards shallowing probably reflects onlap of the Wilkies Shellbed onto the Patea-Tongaporutu High, a feature which was present in the Pliocene, as shown in figure 6.5.

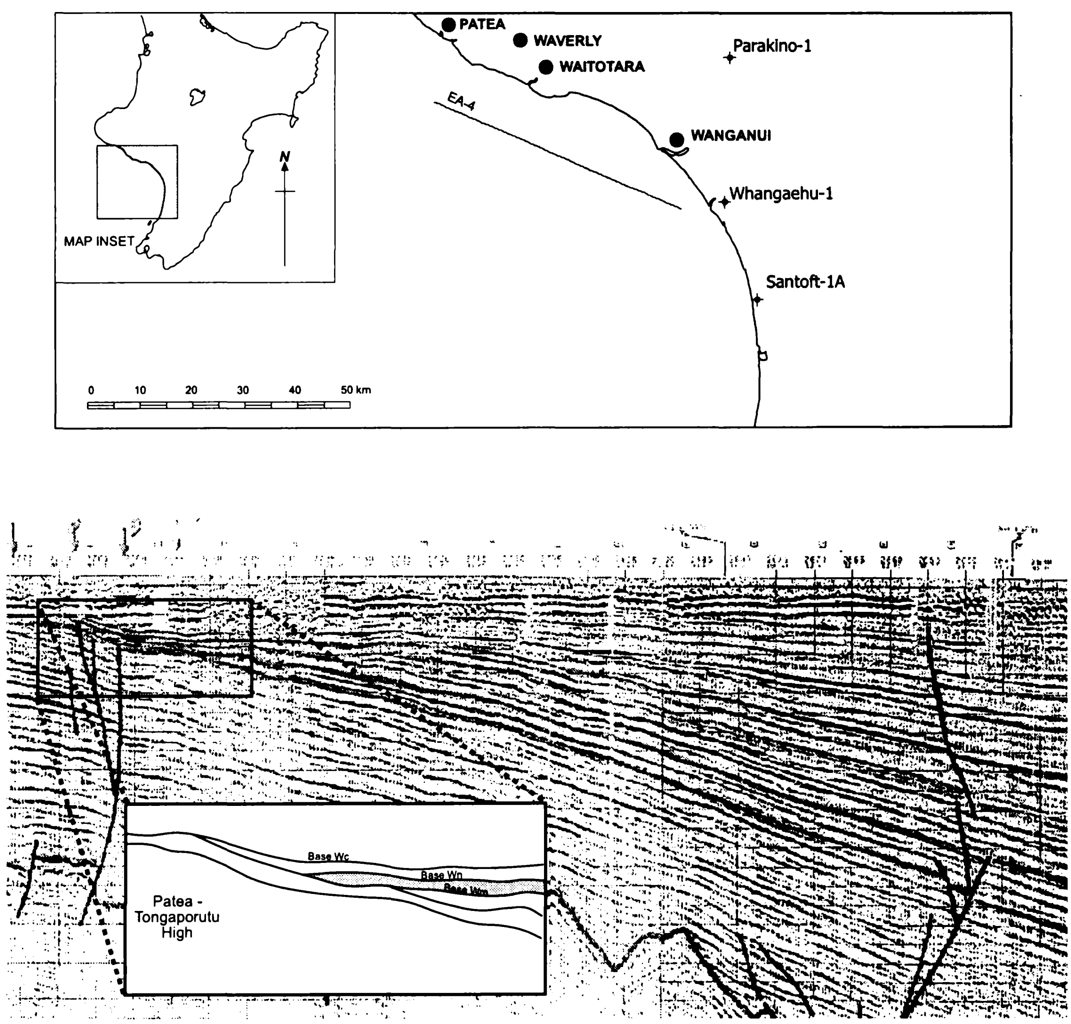


Figure 6.5: Seismic line EA-4 showing eastern flank of Patea-Tongaporutu High, and relationship of contacts between Pliocene units onlapping it. Mangapanian strata are shaded grey in inset.

Sequence Stratigraphic Interpretation.

The relative rise and fall of sea-level indicated by molluscan and facies trends within the Whauteihi Formation suggests that a sequence stratigraphic interpretation can be applied to the succession. The Whauteihi Formation itself can be regarded as a sequence (the fundamental unit of sequence stratigraphy), as it contains a succession of related strata bounded by surfaces of erosion and their correlative conformities (Van Wagoner *et al.* 1988). Thus, the base of the Wilkies Shellbed and the top of the Te Rimu Sandstone are sequence boundaries, and the strata between these horizons can be subdivided into systems tracts. Previous sequence stratigraphic studies of Wanganui Basin strata (Abbot & Carter, 1994; Naish & Kamp, 1997; Kamp & McIntyre, 1999) have focused on individual sections in a one-dimensional sense. Here, the opportunity to study the Whauteihi Formation down the depositional paleoslope allows identification of systems tracts by their lateral continuity, geometry, stacking patterns, and the lateral extent of key surfaces - features more difficult to evaluate in a series of sections occupying the same position on the paleoslope, which is the case for the younger Nukumaruan and Castlecliffian strata investigated to date in a sequence stratigraphic context.

Sequence Boundary and key surfaces:

The base of the Wilkies Shellbed is interpreted as a sequence boundary mainly because it is unconformable over part of the basin and passes eastward into a correlative conformity. This unconformity as observed, probably results from wave-planation, as evidenced by the reworked and disarticulated shallow-water faunal assemblage occurring at the base of the shellbed. As the horizon is erosional, it fulfils the requirements of a type 1 sequence boundary in the sense of van Wagoner *et al.* (1988). The Wilkies Shellbed onlaps the unconformity in a regional sense. This unconformity is also referred to as a ravinement surface or transgressive surface of erosion (TSE), formed by wave action against a retreating shoreface during sea-level rise. Thus, the sequence boundary is also a marine flooding surface (MFS), representing an abrupt increase in water depth. In inferred deeper water settings such as the Wanganui River and Parihauhau sections, the correlative conformity (CC) at the base of the shellbed is also a marine flooding surface.

There are no really obvious flooding surfaces within the Wilkies Shellbed that could mark parasequences indicative of stepped sea-level rise. The next most important surface upwards in the sequence is the downlap surface (DLS). This lies at the top of the Wilkies Shellbed and between it and the Cable Siltstone. This surface approximates the maximum flooding surface, which is a conceptual surface that cannot be located physically at one section (Carter *et al.,* 1998). The stratigraphic position of these surfaces within the Whauteihi Formation is shown on Figure 6.4.

Transgressive Systems Tract (TST):

Molluscan and facies evidence in the sections described above shows that the Wilkies Shellbed accumulated in a progressively deepening marine environment. Shallow, high-energy shoreface conditions dominated at its base and passed upwards to lower energy mid-shelf conditions near the upper contact with the Cable Siltstone. Thus, the Wilkies Shellbed is a Transgressive Systems Tract (TST), onlapping and overlying the transgressive surface (TSE). While the Wilkies Shellbed is the thickest shellbed in the Wanganui Basin, it is nevertheless relatively thin when compared with the combined thickness of Cable Siltstone and Te Rimu Sandstone. This asymmetry reflects the different sediment accumulation rate and depositional style of the Wilkies Shellbed compared with the aggradational and/or progradational clinoforms of the siliciclastic units in the overlying parts of the sequence. The top of the TST occurs at the top of the Wilkies Shellbed in the western part of the basin, where proximity to the paleoshoreline means that the transition between the transgressive and regressive phases of deposition was presumably brief. In more basinward settings (e.g. at Mangamahu), however, the top of the TST is less easily located, and probably occurs within the lower part of the Cable Siltstone. This is probably due to the reducing rate of sea-level rise approaching the highstand, resulting in a less condensed and more terrigenous-dominated upper part of the TST at these depths.

The Wilkes Shellbed itself can be further subdivided into two different types of shellbed, both of which correspond to a different carbonate facies. Following the approach of Kidwell (1991), Naish & Kamp (1997) identified four distinct types of shellbed, each of which are formed in different depositional environments and conditions. All four of these shellbed types occur within the Whauteihi Formation. The two belonging within the Wilkies Shellbed are the onlap and backlap shellbeds. The lowermost, bivalve-dominated, sandstone matrix shellbed in and to the west of Kauarapaoa valley is an onlap shellbed, deposited in a high-energy, shallow marine setting during transgression, onlapping the ravinement surface or TSE. The mechanism responsible for carbonate accumulation within the onlap shellbed is winnowing and bypassing of terrigenous material from the nearshore environment basinwards, leaving a shell lag or gravel. The sandstone channels within the Wilkies Shellbed in the Parikino, Wairangi and Kauarapaoa valley sections can thus be classified as shore-connected sediment wedges or packages (SCW). These are interpreted as containing sediment reworked basinwards from the shoreface environment, merging into the onlap shellbed in a shoreward direction, and overlying the onlap shellbed basinwards.

The deeper-water *Crassostrea* "reef" facies overlying this shellbed in the west, and comprising the entire shellbed in the Parihauhau and Wanganui River valleys, is a backlap shellbed (backstep of Kidwell, 1991). It is formed at the distal toe of retrogradational parasequence sets, where turbidity and rate of sediment accumulation are low. During transgression, the backlap shellbed migrates shoreward, maintaining depths in which molluscs can live in *situ,* usually within a siltstone matrix. In this case, the Wilkies Shellbed represents a unique environment in which *Crassostrea* dominated over the other molluscs normally occurring in this type of shellbed (e.g. *Phialopecten, Crepidula,* brachiopods).

Highstand Systems Tract (HST):

Facies analysis (above) shows that the featureless, blue-grey siltstone (Cable Siltstone) overlying the Wilkies Shellbed accumulated in greater water depths than either the underlying Wilkies Shellbed or the overlying Te Rimu Sandstone. This inference means that the Cable Siltstone accumulated during sea-level highstand conditions, and thus can be generally correlated with the Highstand Systems Tract (HST). As mentioned above, the contact between the Wilkies Shellbed and the Cable Siltstone marks the Downlap Surface (DLS), and thus the base of the HST. This interpretation is consistent with the finest-grained facies in the sequence occurring at the base of the Cable Siltstone in most of the studied sections, indicating the greatest water depth. Furthermore, the occurrence of scattered fossil molluscs in the base of the Cable Siltstone at Mangamahu is regarded as a downlap shellbed, formed by minor stratigraphic condensation at the distal toe of the progradational clinoform overlying the downlap surface (DLS). The top of the HST cannot be located confidently given the available data. However, comparisons between this sequence and the Mangapani Shell Conglomerate and Hautawa Shellbed sequences (Chapters 5 and 7) indicate that the top of the HST is probably in the stratigraphic vicinity of the gradational contact between the Cable Siltstone and Te Rimu Sandstone and cutting across the facies boundary. This positioning is based on the patterns of sequence architecture for siliciclastic sediment above a backlap shellbed, which is further explained in chapter 8.

Regressive Systems Tract (RST):

The Regressive Systems Tract (RST) was proposed by Naish & Kamp (1997) for sediments deposited during the middle stages of regression, when the rate of relative fall in sea-level exceeds the rate of basin subsidence, and accommodation is progressively reduced. The RST follows the HST, and the top is either conformable with an overlying Lowstand Systems Tract (LST) or unconformably bounded by a sequence boundary. In this case, the Te Rimu Sandstone as seen in the Kauarapaoa, Wanganui River and Parihauhau sections is classified as an RST. Shellbeds are also rare in RSTs, but a thin (0.1 m) shell horizon within the Te Rimu Sandstone at Parikino is interpreted as a toplap shellbed, formed either by scattering of the shoreface fauna over the shelf during cyclonic activity, or by bypassing of sediment resulting in localised condensation (Kidwell, 1991).

The positioning of the Whauteihi Formation strata into a sequence stratigraphic framework is illustrated in figure 6.4. This figure is drawn by interpolating the geology between section logs arranged from east to west. Some conceptual time lines are drawn on the figure to illustrate time-space relations between lithofacies, and system tract boundaries must parallel these time lines. Only a few time lines are drawn on the figure, but they show that different facies accumulated simultaneously on the paleoshelf. This is especially evident in the upper parts of the sequence, where sandstone was depositied in the west concurrently with siltstone accumulation in the east. No time lines are plotted within the Wilkies Shellbed, but they are expected to parallel the correlative conformity in the eastern part of the basin where the base of the Wilkies Shellbed is conformable. Where the base of the Wilkies Shellbed is unconformable, time lines would onlap the sequence boundary in a generally westward direction. The positioning of the Downlap Surface (DLS) at the contact between the Wilkies Shellbed and the Cable Siltstone means that the Wilkies Shellbed comprises the TST. In this example, the Cable Siltstone can be loosely placed within the HST, and the Te Rimu Sandstone within the RST. The boundary between these two systems tracts will parallel a time line, as illustrated in figure 6.4 as a dashed line. This horizon is chosen as the HST / RST boundary because sequence stratigraphic interpretation of other sequences (Mangapani Shell Conglomerate, Hautawa Shellbed) suggests that the basinward limit of sandstone in the upper part of a sequence probably accumulates during the latest stage of falling sea-level, and is thus an RST. This reasoning is explained in greater detail in Chapter 8. The unconformity in the western part of the basin precludes sequence stratigraphic classification of the sequence in that area.

Discussion.

The thickness of the Whauteihi Formation in various sections across the basin is fairly uniform. This indicates that the modern subaerial exposure of the formation is more nearly representative of a shore-parallel transect than of a shore-normal cross-section. Further evidence for this is the extent of the *Crassostrea* "reef" within the Wilkies Shellbed. While it thins slightly to the west, it maintains a fairly constant thickness and facies for 14 km, a distance that makes a shore-normal cross-section unlikely. Compared with the Wilkies Shellbed, the School Shellbed has significant *Crassostrea* "reef" development only at one locality, within the Kauarapaoa valley section. Unfortunately the School Shellbed is truncated by the Nukumaruan Kuranui Limestone between this locality and the next section to the west (Wairangi), so the full extent of the *Crassostrea* "reef" facies is unknown. However, the *Crassostrea* part of the School Shellbed thickens from less than 1 m at Parikino to about 7 m at Kauarapaoa, a distance of 6 km, and the Wilkies Shellbed thickens from 1.5 m at Paparangi to 10 m at Wairangi, a distance of ~ 5 km. Because the Wilkies Shellbed shoaled westward, and the School Shellbed shoaled eastward, each shellbed can be used to approximate each other's expected facies and sequence architecture in sections where they are either missing of incomplete. This is illustrated in figure 6.6, which shows the likely position of each shellbed in relation to the shoreline and their *Crassostrea* biostromes.

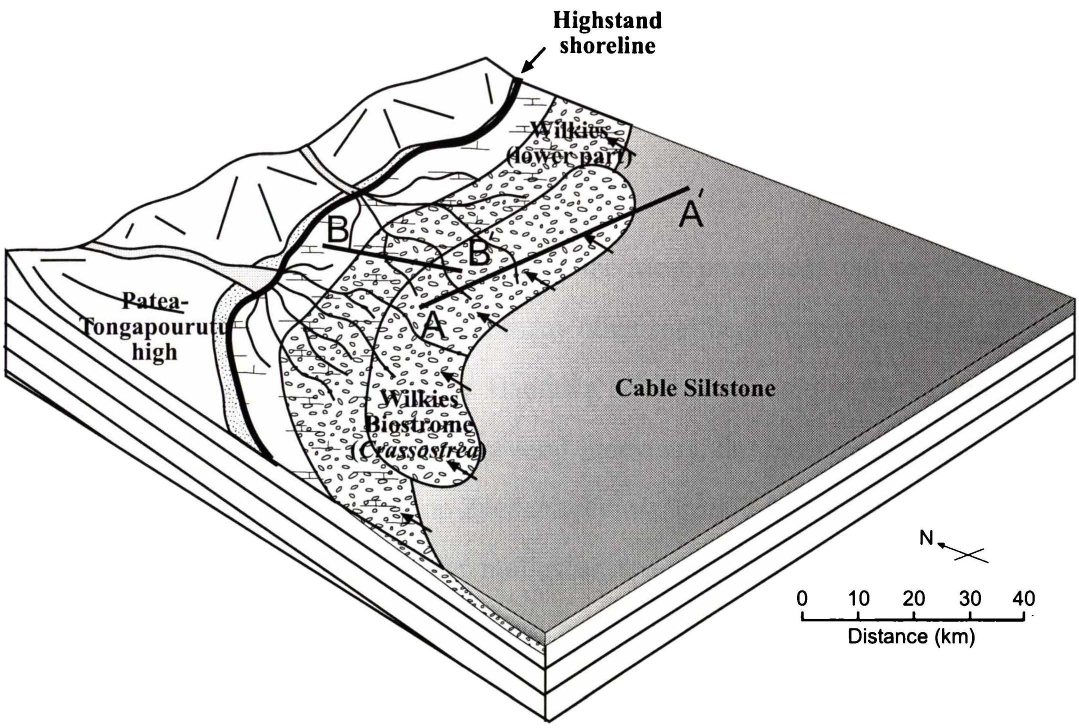


Figure 6.6: 3-dimensional paleogeographic reconstruction showing position of Wilkies Shellbed with respect to the northern shoreline of Wanganui Basin and transect (A-A') through which current exposure is inferred. The figure depicts the shellbed immediately after its growth, in the late part of the transgression in which it formed. Transect B-B' shows a likely conceptual position of the School Shellbed in relation to the shoreline, and to the Wilkies Shellbed.

Assuming 41 k.y. periodicity of the cyclothem which comprises the Whauteihi Formation (Chapter 4), the time missing in the unconformity between the Whauteihi and Whakaihuwaka Formations can be estimated. Since the sequence can be separated into transgressive and regressive phases, accumulation of the Wilkies Shellbed took approximately 20 k.y., with the Cable Siltstone and Te Rimu Sandstone also deposited over ~ 20 k.y. Thus, the amount of missing section within the sequence is a function of time, and can be quantified at each locality where the Whauteihi Formation has been truncated. In and to the east of Kauarapaoa valley, the formation appears to be largely complete, and so the time missing in the unconformable contact between the Whauteihi and Whakaihuwaka Formation is negilible. However, at Paparangi all but 2 m of the Cable Siltstone has been eroded, meaning that slightly less than 20 k.y. separates the strata above and below the unconformity. At Okiwa, the unconformity has cut down into the backlap part of the

Wilkies Shellbed, implying a loss of slightly more than the sediment that accumulated during 20 k.y. at this locality. This is illustrated on figure 6.4 by separating the strata on both sides of the unconformity, as a gap that widens westward.

CHAPTER SEVEN:

CROSS-BASIN FAUNAL, FACIES AND SEQUENCE ANALYSIS OF THE HAUTAWA SHELLBED.

Introduction.

The Hautawa Shellbed (late Pliocene) is one of the most prominent and well-known fossil beds of Wanganui Basin. While there are many other shellbeds within the basin, often with similar character and composition, the Hautawa Shellbed is unique for several reasons. Firstly, the shellbed is co-incident with several bioevents, the most notable being the first occurrence of the subantarctic scallop *Zygochlamys delicatula* in Wanganui Basin, and the extinction of a number of warm-water molluscan species. Thus, the shellbed contains a record of late-Pliocene ocean climate change, and these bioevents aid in correlation of the shellbed between sections across the basin. Secondly, it is one of few shellbeds that occurs across almost the entire width of the basin, from near the coast north of Wanganui City, to near the Manawatu Gorge in central North Island, a distance of over 100 km. Thirdly, the shellbed is one of the thickest of the late Pliocene shellbeds in the basin, making it prominent in the stratigraphy. Previous work by Naish (1996) has demonstrated that the Hautawa Shellbed and the terrigenous units overlying it (Tuha Siltstone and Upokonui Sandstone) comprise a Vail-type sequence. In this study the shellbed as well as the rest of the sequence are investigated.

Purpose of Study:

This chapter investigates how the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone can be traced along strike to reconstruct a late–Pliocene cross-shelf profile for the basin. In addition to reconstructing the shelf profile, the quality of the outcrop and the resolution of the depositional environment of the fauna are such that the architecture of the sequence can be reconstructed with confidence from inner to outer shelf depths on the contemporary shelf. Previous studies (e.g. Abbott & Carter, 1994; Naish & Kamp, 1997; and Saul *et al.* 1999) have reconstructed shelf architectures by putting together parts of different sequences because no other Nukumaruan or Castlecliffian sequence can be traced so continuously across the basin. This chapter aims to demonstrate that the facies, paleontology, and thickness of the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone are not uniform across the basin, and that these variations can be quantified by depth analysis constrained by the fossil and lithofacies content. A sequence stratigraphic template is imposed on a two-dimensional facies distribution of the succession and this highlights its evolution.

History:

The Hautawa Shellbed did not feature in any of the early studies of sediments in Wanganui Basin because it did not extend westwards to the coast where the reasearch focused intially (e.g. Marshall & Murdoch, 1920). Feldmeyer *et al.* (1943) first identified the shellbed near Hunterville, and mapped it westward into the Turakina, Mangawhero and Wanganui River valleys. In that study, it was named the "Hautawa Reef Horizon", and fossils were collected from what subsequently became the type section on Old Hautawa Road (T22/ 325484). Fleming (1944) reported the first occurrence in the basin of the cold–water scallop *Zygochlamys delicatula* in this collection, and assigned it a Nukumaruan age, despite the base of the stage not being formally defined at the time. In "The Geology of Wanganui Subdivision", Fleming (1953) mapped the Hautawa Shellbed from the Turakina valley to the Kauarapaoa Stream section and suggested how it is related to the Kuranui Limestone in the westernmost part of the basin. Fleming (1953) identified multiple molluscan bioevents within the Hautawa Shellbed, and formally defined the Hautawan Substage of the Nukumaruan Stage, the lower of the two Nukumaruan substages, and based on the Hautawa Shellbed. The concept of a Hautawan Substage has not proved to be useful and has largely been abandoned (Boreham, 1963; Beu, 1969; 1970; 1995, Vella & Nicholl, 1970). The base of the Nukumaruan Stage is clearly understood to be defined at the base of the Hautawa Shellbed (e.g. Beu, 2001).

Fleming suggested that the Kuranui Limestone (found only in the western parts of the basin) correspond to the Hautawa Shellbed. However, he did not correlate it directly with the Hautawa Shellbed, but with the overlying Upokonui Sandstone (a unit found *above* the

Hautawa Shellbed in the central parts of the basin), suggesting that the Hautawa Shellbed was missing in the unconformity beneath the Kuranui Limestone. This assumption was adopted by Boreham (1963), who correctly pointed out that fossil differences were minimal between the Mangapanian and Nukumaruan Stages in western Wanganui Basin, especially when *Zygochlamys delicatula* was not present. This problem has been alleviated by advances in the understanding of the Pliocene *Phialopecten* lineage by Beu (1995).

Although the Hautawa Shellbed is mentioned in several papers published during the 1970s and 1980s (e.g. Collen, 1972; Ker, 1973; Beu & Edwards, 1984; Beu *et al.*, 1981) none of these focused on Hautawa Shellbed in any great detail. The Hautawa Shellbed has been briefly described in the following papers: Naish & Kamp (1995; 1996; 1997) and Kamp & Naish (1997) for the Rangitikei region, and McIntyre & Kamp (1998) and Kamp & McIntyre (1998) for the Wanganui River valley.

Stratigraphic Context:

The Hautawa Shellbed is one of many late Pliocene shellbeds in Wanganui Basin, but it is especially significant for several reasons. Firstly, it is associated with multiple bioevents, both molluscan and foraminiferal. These events mark a rapid cooling, in which an estimated 5% of New Zealand molluscan genera became extinct (Beu, 1990), and mark the first occurrence of the subantarctic scallop *Zygochlamys delicatula* in the basin. Furthermore, the shellbed marks a return to shelfal conditions across the entire basin, following intervals of tectonically driven deepening in the late Waipipan and early Mangapanian.

The Hautawa Shellbed is best exposed in river sections in central-inland Wanganui Basin (Figure 7.1). It crops out semi-continuously between the Rangitikei River and Kauarapaoa valleys. Between these sections, the landscape is highly dissected, with shellbeds cropping out mainly in road cuts and clean bluffs above rivers and streams. It strikes 110° across the basin. West of Paparangi, the strike swings around to ~ 055°, where the shellbed passes into Kuranui Limestone. Throughout most of the basin, the shellbed and Kuranui Limestone dip consistently southwards at 4-5°. Fleming (1953) used the Hautawa Shellbed as the boundary between the Lower and Upper Okiwa Groups. In this study, the name Okiwa Group is retained for the succession of Mangapanian shelfal cyclothems immediately beneath the Hautawa Shellbed, and emend the Rangitikei Group of Te Punga (1953) and Naish & Kamp (1995) to extend from the base of the Hautawa Shellbed to the top of the Ohingaiti Sandstone / Nukumaru Limestone (Chapter 2). This modification has been made because the base of the Hautawa Shellbed is one of the most mappable and extensive horizons in Wanganui Basin, and can be correlated confidently between sections. In addition, it marks the base of the Nukumaruan Stage.

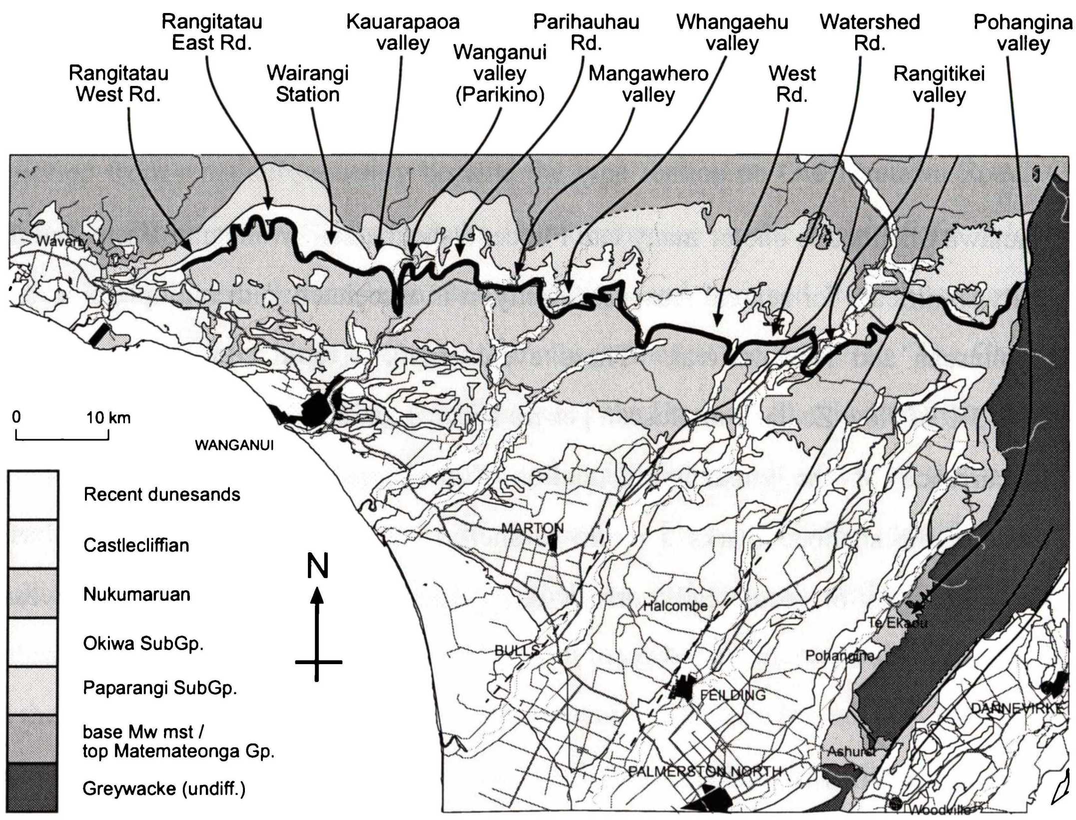


Figure 7.1: Map of Wanganui Basin showing localities where the Hautawa Shellbed crops out. Thick line shows outcrop transect.

Relative Dating (Biostratigraphy).

Bioevents marking the Mangapanian / Nukumaruan boundary are chiefly molluscan. The currently recognized datums for this boundary in Wanganui Basin are shown in Table 7.1.

Table 7.1: Molluscan biostratigraphic datums identified in Wanganui Basin for the Mangapanian (Wm) / Nukumaruan (Wn) boundary.

<table>
<tr><th>Mangapanian
(LO)</th><th>Base of Hautawa
Shellbed</th><th>Nukumaruan
(FO)</th></tr>
<tr><td rowspan="3"></td><td colspan="2">Zygochlamys delicatula</td></tr>
<tr><td colspan="2">Mesopeplum convexum</td></tr>
<tr><td colspan="2">Phialopecten triphooki</td></tr>
<tr><td colspan="2">Crassostrea ingens</td><td rowspan="7"></td></tr>
<tr><td>Polinices (s.s.)</td><td rowspan="6"></td></tr>
<tr><td>Clavatoma pulchra</td></tr>
<tr><td>Maoricardium spatiosum</td></tr>
<tr><td>Alcithoe gatesi</td></tr>
<tr><td>Austrofusus pagoda</td></tr>
<tr><td>Phialopecten thomsoni</td></tr>
</table>

The overlap between the last occurrence of the giant oyster *Crassostrea ingens* and the first occurrence of Nukumaruan scallops shows that the giant oyster survived into the early Nukumaruan. The FO of the scallop *Zygochlamys delicatula* is the primary criterion for the base of the Nukumaruan Stage, and thus the dual occurrence of *C. ingens* and *Z. Delicatula* in Wanganui Basin marks the very earliest Nukumaruan. Only one foraminiferal bioevents has been found at the Mangapanian / Nukumaruan stage boundary in Wanganui Basin, with the FO of the planktic foram *Globorotalia crassula* (1 juvenile specimen) was recognised in the Hautawa Shellbed in the Mangawhero River valley section (Hornibrook, 1981).

Numerical Dating.

To establish the age of the Mangapanian / Nukumaruan stage boundary, we follow the approach of Naish *et al.* (1996) and integrate paleomagnetic transitions with isotope stage assignments. To do this, we integrate paleomagnetic data from three sections; the Rangitikei River valley (from Naish *et al.* 1996), the Turakina River valley (Kamp *et al.* in prep) and Wanganui River valley. The data for these sections have been re-interpreted by Kamp *et al.* (in prep), using the methodology outlined in Turner (2001). As demonstrated in Chapter 4, this gives an extrapolated age of 2.32 Ma for the Hautawa Shellbed, which can then be modified by using isotope stage matching for successive cyclothems above the Gauss / Matuyama transition (assuming 41 k.y. cyclicity) to correlate the strata with the oxygen isotope timescale. This method gives a match between the shellbed and Stage 88, giving an age of 2.28 Ma for the Wm / Wn stage boundary, as illustrated in figure 7.2. This is comparable with the assignment of the Wm / Wn boundary in the Mangaopari Stream section in south–eastern North Island (Orpin *et al.* 1998) with Stage 86-87.

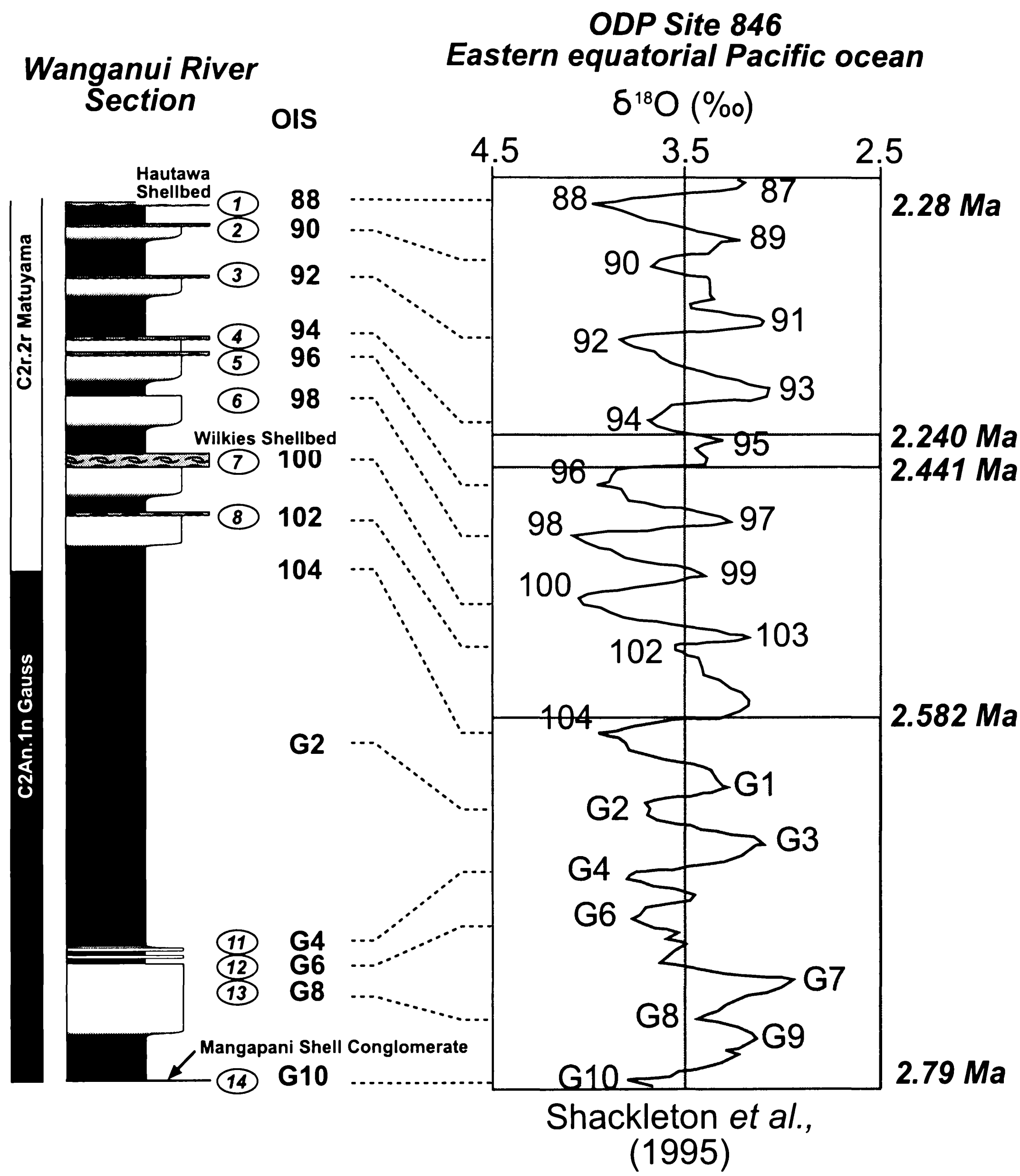


Figure 7.2: Correlation of Mangapanian Stage strata in Wanganui River valley with the oxygen isotope curve for ODP site 846. This interpretation shows a match between the Hautawa Shellbed and OIS 88, giving an age of 2.28 Ma for the shellbed.

Section Descriptions and Facies Characteristics.

The Hautawa Shellbed occurs across the width of most of the Wanganui Basin. Consequently, it comprises a variety of different facies, with conglomerate–rich shellbeds in the east, shell coquinas in central parts, and shelly limestones in the west. The following localities have been selected for their accessibility and position along the strike of the shellbed. Also described are the terrigenous units (Tuha Siltstone and Upokonui Sandstone) belonging to the cyclothem that has the Hautawa Shellbed at its base. Because the emphasis of this study is more on lateral rather than vertical facies and faunal trends, the facies and stratigraphic characteristics of each unit in each section have been noted and coded to establish any lateral directional trends in the various facies exists. Additionally, particular attention has been placed on the molluscan faunal assemblages from the Hautawa Shellbed (and to a lesser extent the terrigenous units) for two main reasons: 1) to quantify the various changes in relative sea-level throughout the succession for each section and to better understand the depositional paleoenvironment and paleoecology; and 2) to investigate if and how each of these parameters change across the paleoshelf.

Historical and updated faunal lists for the Hautawa Shellbed for localities across the basin are contained in Appendix 1. Facies codes are explained in Table 7.2.

Table 7.2: (facing page) Facies groups and lithofacies codes used for describing the Hautawa Shellbed and associated lithologies, Wanganui Basin.

Groups	Lithofacies code	Description	Typical example	Depositional environment
Siltstone Group	Z_1	Barren to sparsely fossiliferous, massive bioturbated siltstone	Tuha Zst, Whangaehu	Mid-shelf
	Z_2	Barren to sparsely fossiliferous, massive, bioturbated fine sandy siltstone	Tuha Zst, Parihauhau	Inner–mid shelf
	Z_3	Barren to sparsely fossiliferous alternating centimeter to decimetre siltstone and fine sandy siltstone beds (silt dominant)	Zst beneath Hautawa, Mangawhero	Inner-shelf, possibly estuarine
Sandstone Group	S_1	Barren to sparsely fossiliferous, massive, bioturbated, silty fine sandstone	Sst beneath Hautawa, Parikino	Inner-shelf
	S_2	Barren to moderately fossiliferous, bioturbated, massive fine micaceous sandstone	Base Upokonui, Kauarapaoa	Shoreface
	S_3	Barren, wavy laminated siltstone and fine sandstone (sand dominant)	Top Upokonui, Rangitikei Riv.	Inner-shelf
	S_4	Barren to moderately fossiliferous, bioturbated, decimeter scale horizontally bedded fine sandstone	Upokonui Sst, Mnagawhero	Inner-shelf
	S_5	Horizontally bedded to low–angle planar cross–stratified, bioturbated fine–medium sandstone	Upokonui Sst, Parihauhau	Shoreface
	S_6	Barren to moderately fossiliferous, bioturbated, uncemented fine–medium sandstone with *Fellaster* within decimeter scale tabular concretionary flags	Top Upokonui Sst, Parikino and Kauarapaoa	Shoreface
	S_7	Barren, bioturbated, trough cross – bedded sandstone with decimeter scale blocky concretionary flags	Base Upokonui Sst, Rangitatau West Rd.	Shoreface
Shellbed Group	Cz_1	Clumps and bands of in / near situ shells (*Pratulum, Atrina, Chlamys*) within bioturbated massive siltstone. Matrix dominated	Within Hautawa Shell-bed, Parikino	Outermost inner-shelf
	Cz_2	Closely packed shells (*Ostrea, Purpurocardia, Crepidula, Crassostrea* Brachiopods) within bioturbated fine sandy siltstone. Shell dominated	Top Hautawa Shellbed, Parikino	Outermost Inner-shelf – mid-shelf
	Cz_3	Dispersed, matrix supported near – in *situ* shells (*Alcithoe, Antalis, Pelicaria, Pratulum*) within bioturbated siltstone	Base Tuha Zst, Watershed Rd.	Mid-shelf
	Cs_1	Closely packed shells (typically bivalves – *Eumarcia, Dosinia, Gari, Divaricella, Pteromyrtea*) within bioturbated silty sandstone and sandstone	Base Hautawa Shellbed, Parikino	Inner-shelf
Conglomerate Group	Cg_1	Cross – bedded, closely packed lensiodal conglomerate comprising well rounded greywacke cobbles and shell fragments (*Glycimeris, Cellana, Crassostrea*) in coarse sand matrix	Basal Conglomer-ate, Te Ekaou Stm., Pohangina.	Rocky shoreface
	Cg_2	Horizontal to low – angle cross- bedded conglomerate with well – rounded greywacke pebbles and shells (*Paphies, Glycimeris, Phialopecten, Purpurocardia*) within medium sand matrix	Glycimerid Conglomerate, Te Ekaou Stm., Pohangina	Inner-shelf, proximal to rocky shoreline.
Limestone Group	Cl_1	Cross –bedded, flaggy, pebbly, shell hash limestone with rare *Phialopecten, Mesopeplum*, and *Ostrea.* with moulds and casts of *Atrina* and *Crepidula* common	Kuranui Lime-stone, Rangitatau West Rd.	Inner-shelf

Te Ekaou Stream Section, Pohangina valley: (Figure 7.3a)

Carter (1972) reported the occurrence of Mangapanian / Nukumaruan shelly conglomerates over basement at site 72 (T23/577174) on the western flank of the Ruahine Range in the Pohangina valley, but did not correlate any unit directly with the Hautawa Shellbed. In the Te Ekaou Creek section the lowermost conglomerate bed is poorly sorted, with rounded greywacke cobbles up to 50 cm in length interspersed with a diverse nearshore fauna including *Cellana, Crassostrea, Ostrea, Phialopecten thomsoni, Tawera subsulcata, Zethalia coronata* and *Teguloryncha.* The unit is lensoidal, and up to 2 m thick, occuring as isolated pockets in local depressions on basement (facies Cg_1). Carter (1972) named this unit the "Basal Conglomerate Member". The faunal assemblage gives a Mangapanian age for the unit. The upper part of this unit is a finer-grained (5-6 mm diameter) greywacke pebble conglomerate, 3 m thick, named the "Glycimerid Conglomerate Member", which has a slightly different character (Cg_2). Shells associated with these pebbles, being iron–stained, indicate an advanced stage of dissolution. Weathered, thick-shelled bivalves and scallops (*Tucetona, Purpurocardia, Phialopecten*) are the only taxa preserved. Carter (1972) reported the FO of *Zygochlamys delicatula* at the top of the Basal Conglomerate Member, within a transitionary zone of about 2 metres in which both Mangapanian and Nukumaruan molluscs occur. This locality was revisited during fieldwork for this study, and since no discernable sedimentary break was found between the Basal and Glycimerid Conglomerate members, it is considered that they are both correlatives of the Hautawa Shellbed. Conformably overlying the conglomeratic shellbeds is a 58 m-thick blue–grey massive siltstone (facies Z_1) in which *Pelicaria convexa* is common throughout. The siltstone appears to be a deep-water equivalent of the Upokonui Sandstone, and becomes sandier at the top of the unit (facies Z_2).

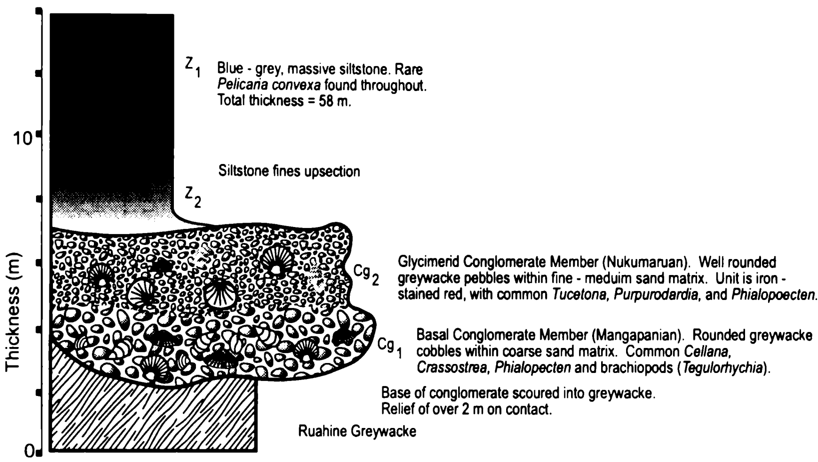


Figure 7.3a: Basal Nukumaruan Conglomerates, Te Ekaou Stream, Pohangina valley.

Rangitikei River Section: (Figure 7.3b)

The Hautawa Shellbed has been mapped across the Rangitikei River (Naish & Kamp, 1995). It crops out very poorly in a small cutting beneath the low terrace at T22/436457. There it is a 0.2 m thick, weathered shellbed containing a diverse fauna including *Atrina, Ostrea, Pratulum, Caryocorbula, Calliostoma, Penion, Amalda* and *Antalis* (facies Cz_2). *Zygochlamys delicatula* was also recovered from this locality. No bedding features can be seen in the shellbed. The base of the shellbed is conformable with an underlying 2 m-thick massive sandy siltstone (facies S_1). The Tuha Siltstone conformably overlies the top of the shellbed, and is a 45 m thick massive, barren, bioturbated blue–grey siltstone (facies Z_1), containing clumps of *Amygdalum striatum, Pratulum pulchellum,* and *Panopea* (facies Cz_1). This siltstone coarsens upsection via a zone of interbedded siltstone and sandy siltstone into the Upokonui Sandstone (Tuha Sandstone of Feldmeyer *et al.*, 1943; Fleming, 1953, and Naish & Kamp, 1995), which in this section is a 32 m-thick, grey–brown uncemented fine sandstone (facies S_5). The Upokonui Sandstone is mainly comprised of low–angle cross beds in the lower 28 m which grade into flaser beds in the upper 4 m (facies S_2) (Naish & Kamp, 1995). Common fossils in the upper part of the sandstone include *Gari, Scalpomactra, Panopea* and *Fellaster zelandiae* (Naish & Kamp, 1995). The Tuha Shellbed unconformably overlies the Upokonui Sandstone.

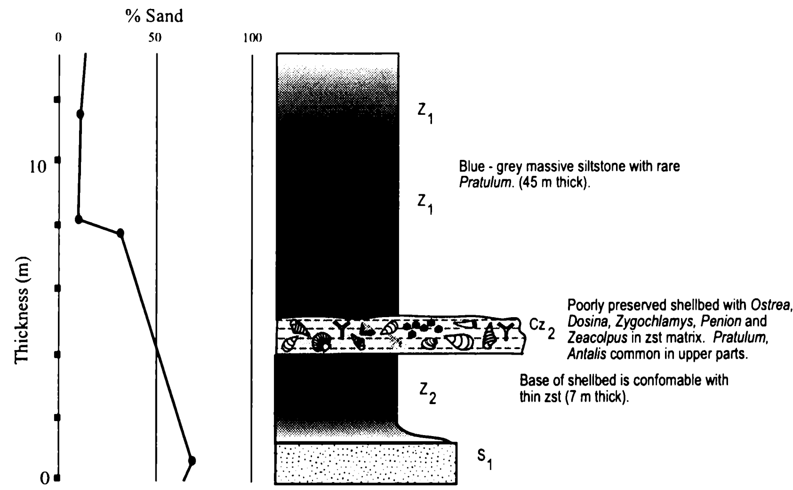


Figure 7.3b: Hautawa Shellbed, river outcrop, Rangitikei River valley.

Watershed Road section: (Figure 7.3c)

In the Watershed Road section at T22/371473, the Hautawa Shellbed is ~ 2 m thick but is poorly exposed in a road cutting. It conformably overlies Okiwa Subgroup sandy siltstone with relief of ~ 0.5 m on the contact. The unit is most fossiliferous near the base, with reworked mussels (*Aulacomya, Perna*), oysters (*Anomia, Patro, Crassostrea, Ostrea*), scallops (*Chlamys, Zygochlamys*) and *Purpurocardia* being the dominant taxa. Fossils in the lower part of the shellbed appear to be slightly current-bedded, with *Ostrea* and *Purpurocardia* typically densely packed into a medium sandstone matrix (facies Cz_2). The upper part of the shellbed is slightly less fossiliferous, with *in situ* gastropods (*Bathytoma, Amalda*) and schaphopods *Antalis* common in the silty matrix.

The top of the shellbed grades sharply into the Tuha Siltstone, with *Splendrillia*, *Alcithoe* and *Antalis* occurring in the base of the siltstone (facies Cz_3). Here, the Tuha Siltstone is 70 m thick, and crops out as a moderately well cemented, white–grey, sparsely fossiliferous, massive siltstone (Z_1), which grades upwards into the Upokonui Sandstone. The Upokonui Sandstone in this section is 18 m thick, and more massive in appearance than in the Rangitikei River section – i.e. facies S_3 (Naish & Kamp, 1995).

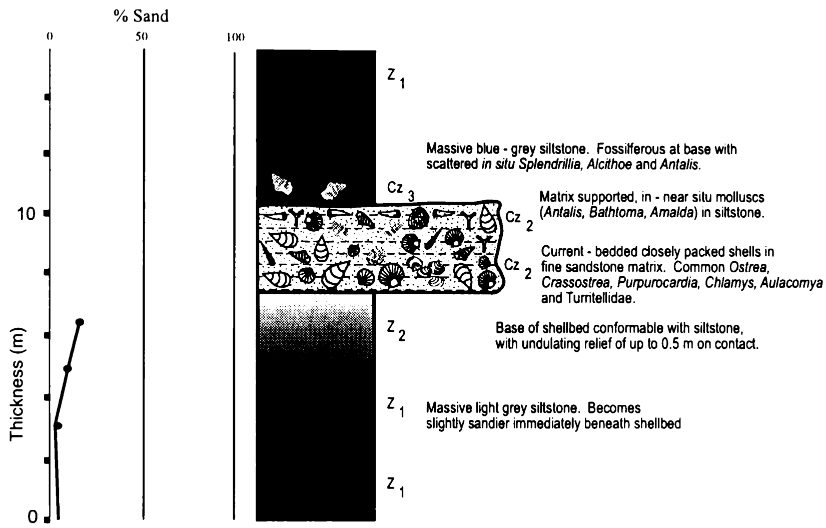


Figure 7.3c: Hautawa Shellbed, Watershed Rd., Ohingaiti.

West (Old Hautawa) Road, Porewa valley (type section): (Figure 7.3d)

The Hautawa Shellbed is very well exposed in this section, cropping out near-continuously above and beside the disused Old Hautawa Rd, which is now a graded farm track. The type section itself is at T22/325484, where the shellbed is 2 m thick, and conformably overlies massive Mangapanian Siltstone (facies Z_1). The lower 0.5 m of the shellbed is comprised of tightly packed molluscs (*Crassostrea, Chlamys, Purpurocardia, Ostrea*) within a fine sandstone matrix (facies Cs_1). The conformable contact with the underlying siltstone is shown by the interdigitation of more and less fossiliferous siltstone bands. The shellbed becomes less fossiliferous in the upper parts, where brachiopods (*Teguloryncha, Neothyris*) and bryozoans are abundant (facies Cz_2). The top of the shellbed is sharply overlain by the Tuha Siltstone, which in this section is 70 m thick, and has a pale grey appearance (Naish & Kamp, 1995).

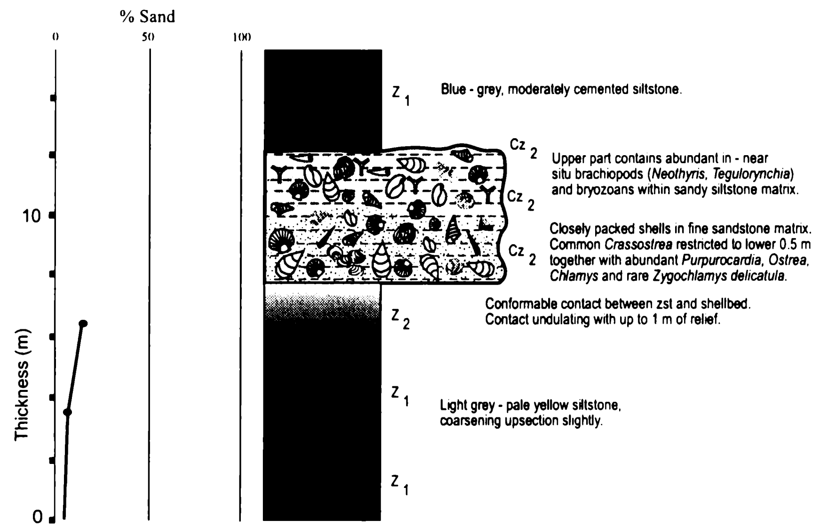


Figure 7.3d: Hautawa Shellbed, West Rd, Porewa valley (type section).

Whangaehu River valley section: (Figure 7.3e)

The Hautawa Shellbed crops out in several localities in the Whangaehu River valley. The best exposure is on Ridge Rd (now disused) at S22/143534 (GS 4355; Fleming, 1953), Whangaehu valley roadside (S22/121524) and Creek Rd at S22/145521 (GS 4369; Fleming, 1953). The shellbed ranges in thickness from 2.5–3 m, and is well exposed in bluffs overlooking the Whangaehu River where its prominence is due to cementation combined with a sharp base. The lower contact is unconformable with relief of up to 0.2 m at particular sites, with large shell-filled *Ophiomorpha* burrows extending downwards from the base of the unit into sandy siltstone (Z_2). The fauna appear to have been reworked in the lower part of the shellbed, with scallops and oysters typically disarticulated and positioned convex-upward in a sandy matrix. In the Creek Road section, a fine shell hash (facies Cl_1) occurs in lenses near the base of the unit. Otherwise, preservation of fossils is good, with most specimens generally complete, with the occurrence of fine-shelled species such as *Mylitella* and *Taniella* indicating minimal carbonate dissolution. The lower 0.5–1 m of the shellbed contains a diverse fauna with common *Zygochlamys delicatula* (FO), *Pleuromeris, Purpurocardia, Talabrica, Crepidula* and *Amalda* (Cz_2). *Ostrea, Crepidula, Sigapatella* and brachiopods are common throughout the shellbed, but comprise most of the faunal assemblage in the upper 2 m (also facies Cz_2), which has two parts. The lower part (central part of the shellbed, 0.8 m thick) is dominated by calyptraeids (*Sigapatella, Crepidula*), with the upper 1.2 m unique in containing *Magasella* and *Ostrea.* The top of the shellbed is gradational with the Tuha Siltstone, of which only the lower 40 m is exposed (facies Z_1). A 0.2 m thick, poorly developed shell horizon within the siltstone 16 m above the Hautawa Shellbed contains *Antalis, Pelicaria, Zenatia, Tomopleura, Splendrillia* and *Dosina*, before passing upwards into the sandy siltstone (Z_2) upper part of the Tuha Siltstone. The Upokonui Sandstone was not located.

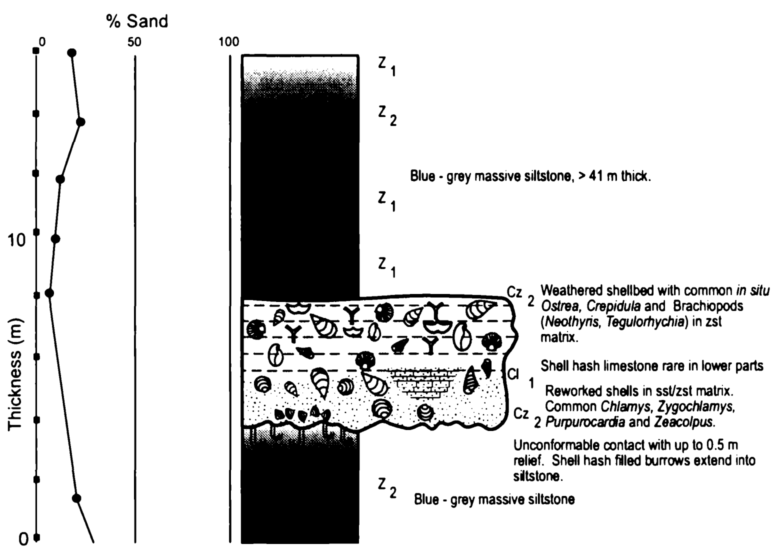


Figure 7.3e: Hautawa Shellbed, Mangamahu, Whangaehu River valley.

Mangawhero River valley section: (Figure 7.3f)

In this section, the Hautawa Shellbed crops out spectacularly in a large bluff about 30 m above SH4 at S22/062537, where it overlies bedded Okiwa Subgroup siltstone (Z_3) unconformably. Here, the shellbed is 3 m thick, and has a similar appearance to outcrops in Whangaehu valley. The faunal assemblage is fairly diverse, with uncommon molluscs such as *Barbatia, Panis, Aeneator* and *Pelicaria.* Species found in abundance throughout the shellbed include *Ostrea chilensis, Chlamys gemmulata* and *Purpurocardia purpurata.* A few disarticulated valves of *Zygochlamys delicatula* are restricted to the lower part of the shellbed, with *Aeneator, Pratulum* and *Taniella* common in the upper parts. The entire shellbed is consistent with facies Cz_2, with only a minor decrease in the grainsize of the matrix from sandy siltstone at the base to siltstone in the upper part. A thin horizon of siltstone (1 m thick, facies Z_2) conformably overlies the shellbed, which in turn is overlain by the Upokonui Sandstone, about 40 m thick at this locality. This sandstone is horizontally bedded with 0.2 m thick alternating beds of sandy siltstone and silty sandstone throughout (facies S_4).

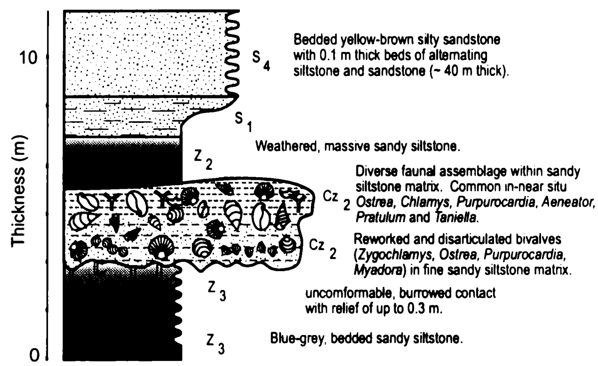


Figure 7.3f: Hautawa Shellbed, Mangawhero River valley.

Parihauhau Road Section: (Figure 7.3g)

The Hautawa Shellbed is both poorly exposed and preserved in the Parihauhau Road section, with talus concealing it in many places. Fleming (1953) collected macrofauna from four sites in the section, none of which could be located during fieldwork for this study. The shellbed itself crops out in a bluff at S22/972554, where it is 3.5 m thick and unconformably overlies featureless blue-grey Mangapanian Okiwa Subgroup siltstone (Z_2), and has been so highly weathered that only brachiopods (mainly *Notosaria* and *Neothyris*) remain (facies Cz_2). Conformably overlying the shellbed is 2 m of barren, massive siltstone (Z_2), which rapidly coarsens upsection into the Upokonui Sandstone. Here, the Upokonui Sandstone is 47 m thick, and crops out as an uncemented, low–angle cross–bedded, yellow–brown micaceous sandstone (facies S_5). The urchin *Fellaster zelandiae* is common in the uppermost 5 m of the sandstone, and extensive *Ophiomorpha* burrows infilled with broken shell fragments occur in a siltstone matrix extending downwards for 1 m into the sandstone from the unconformity at the base of the overlying Tuha Shellbed.

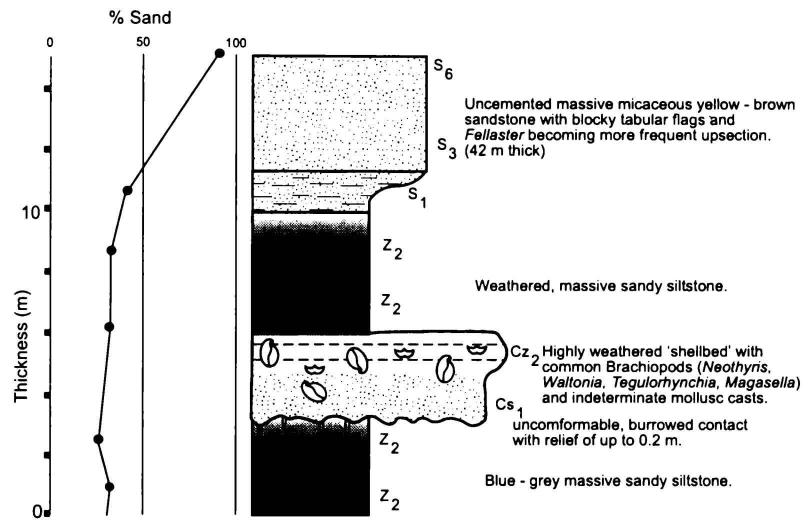


Figure 7.3g: Hautawa Shellbed, Parihauhau valley.

Wanganui River (Parikino) valley section: (Figure 7.3h)

The Hautawa Shellbed is well exposed in the Wanganui River valley, where it crops out at the top of a ridge at S22/963570 and at Parikino at S22/952548 and S22/951546. There are no appreciable differences in thickness or faunal content between these sites, although the base of the shellbed appears to be conformable with the underlying Okiwa Subgroup siltstones (facies Z_2) at S22/963570, whereas it is unconformable in the sections at Parikino. The shellbed is 3 m thick at each locality, with up to 0.3 m of relief on the unconformity where present. Preservation of molluscs in the shellbed is good, with the lower 0.5 m containing a diverse assemblage of densely packed, disarticulated molluscs such as *Pleuromeris, Purpurocardia, Ostrea, Mesopeplum, Chlamys* and *Crepidula* set in a sandy matrix (Cs_1). This passes upwards into a less fossiliferous siltstone (1.5 m thick), which is in turn overlain by an upper shellbed about 1 m thick, in which *Ostrea, Maoricolpus, Atrina, Sigapatella* and brachiopods (*Neothyris, Waltonia, Notosaria*) are common (facies Cz_2). *Zygochlamys delicatula* has been collected from the lower part of the shellbed at Parikino (McIntyre & Kamp, 1998). The shellbed is sharply overlain by the Upokonui

Sandstone, which in this section is a loose, 25 m thick, unconsolidated sandstone with tabular calcite concretions about 0.1 m thick, separated by about 1 m of fine sandstone (facies S_6). The urchin *Fellaster zelandiae* is commonly found in clusters cemented into the upper surface of the concretionary horizons. The top of the sandstone is marked by 1 m of spectacularly dense *Ophiomorphia* burrows infilled with siltstone extending downwards from the top of the sandstone. Unconformably overlying the Upokonui Sandstone is the Tuha Shellbed, which is very poorly preserved at Parikino, with only a few brachiopods and casts of *Calliostoma* remaining.

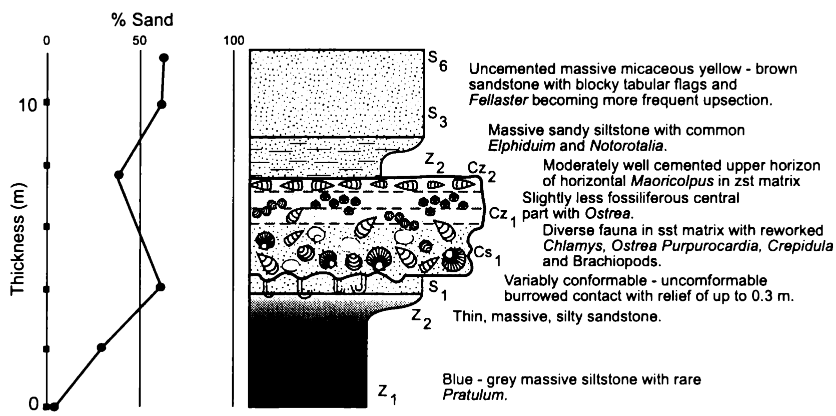


Figure 7.3h: Hautawa Shellbed, Parikino, Wanganui River valley.

Kauarapaoa valley section (Figure 7.3i)

In this section, the Hautawa Shellbed crops out on the eastern bank of the Kauarapaoa Stream about 2.5 km upstream from its confluence with the Wanganui River (R22/900554). It also crops out on the roadside 100 m north of a footbridge across Kauarapaoa Stream at R22/897548. In this section the total thickness of the shellbed is 4 m, separated into two main parts. At these sites the School Shellbed (Mangapanian) is separated from the Hautawa Shellbed by only 1 metre of sparsely fossiliferous siltstone (Z_2). The lower part of the Hautawa Shellbed in the Kauarapaoa valley is very similar to its equivalent in the Wanganui River Section, with well-preserved, diverse fossils horizontally imbricated within a sandy matrix with common *Anomia, Patro, Chlamys, Ostrea, Divaricella, Eumarcia, Crepidula* and *Fellaster* (facies Cs_1). Here, the lower part of the shellbed is up to 2 m thick, and is unconformable with the underlying siltstone. This lower part is conformably overlain by 1 m of weakly bedded siltstone (Z_3), above which is the upper part of the shellbed, which is 1 m thick. The lower part is less fossiliferous and diverse than the lower shellbed, with common *Chlamys, Ostrea, Sigapatella, Xymene, Almada* and the brachiopod *Neothyris* (facies Cz_2). On the roadside outcrop, the shellbed is more compound in nature, with no siltstone separating the two parts of the shellbed. The cold–water scallop *Zygochlamys delicatula* was recovered from this locality, which is the westernmost FO of this important fossil in Wanganui Basin. The Upokonui Sandstone rests conformably upon the shellbed, and in this section is a 42.5 m thick, uncemented, micaceous pale yellow medium sandstone, with three main parts. The lowermost part (22 m thick) is a massive and featureless well-sorted fine sandstone (facies S_3). The central part (12 m thick) is comprised of a low–angle tabular cross– bedded fine sandstone separating thin horizontal concretionary horizons less than 0.1 m thick every 2 m or so (facies S_5). Abundant *Fellaster* within a concretionary horizon marks the boundary between the middle and upper parts of the sandstone. The uppermost 8.5 m thick part of the unit is an extensively bioturbated medium sandstone, with no apparent bedding structures. The micromollusc *Mylitella* is found in the ~1 m thick sandstone intervals separating 0.2 m-thick concretionary flags (facies S_6). The Tuha Shellbed unconformably overlies the Upokonui Sandstone in this section. Fleming (1953) presented a faunal list for the Hautawa Shellbed locality at the top of a hill at R22/893575 (GS 4197). This site was visited during fieldwork for this study, and the Hautawa Shellbed could not be found. However, the "Two shellbeds showing no appreciable faunal differences" he referred to at this site are probably the School and Hautawa Shellbeds. The FO of the Nukumaruan–Recent scallop *Mesopeplum convexum* in his faunal list supports the likelihood of this interpretation.

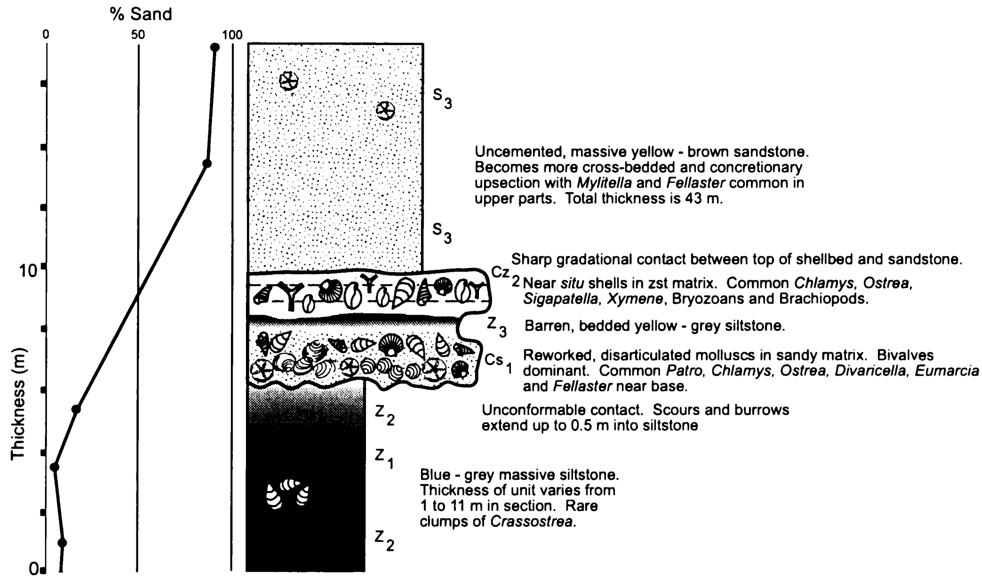


Figure 7.3i: Hautawa Shellbed, Kauarapaoa valley.

Wairangi Station section. (Figure 7.3j)

At Wairangi, the Hautawa Shellbed is not present in the form of a shellbed, but rather as the Kuranui Limestone, a unit considered here to be laterally equivalent to the Hautawa Shellbed. This locality is 9 km to the northwest of the Hautawa Shellbed occurrences in the Kauarapaoa Stream Section. The transition from shellbed to limestone apparently occurs between these sections. The Kuranui Limestone crops out on the top of a hill at R21/ 836611, as a moderately cemented, cross-bedded, flaggy, sandy shell–hash (calcirudite) limestone (facies Cl_1) 7.5 m thick, scoured into Okiwa Subgroup Siltstone (Z_2). Preservation of fossils is poor, but fragments of *Fellaster* are common near the base. One point of note is that the School Shellbed is not present in this section, and it is thought to be missing in the unconformity at the base of the limestone. Strata above the limestone are either not visible or not present at this locality.

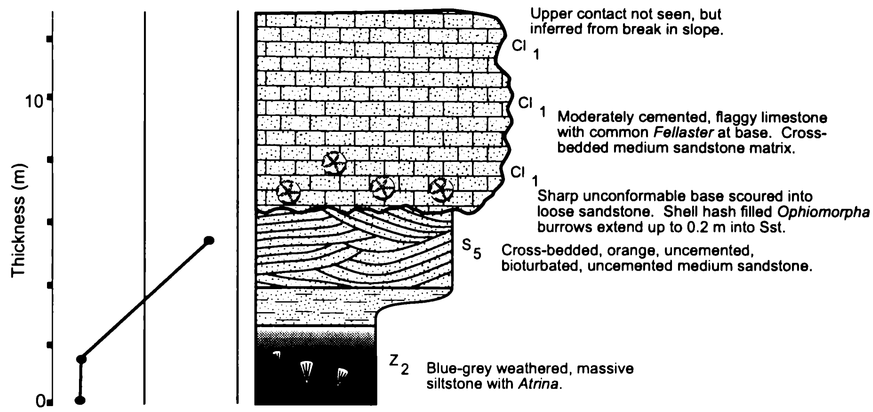


Figure 7.3j: Kuranui Limestone, Old Tokomaru East Rd, Wairangi Station.

Rangitatau East Road (Paparangi) section:

The Kuranui Limestone is well exposed at an abandoned quarry (R21/763628) exposing this section. At this site the limestone is highly weathered, with little primary carbonate remaining. No fossils were collected from this locality, although remnants of *Phialopecten* and *Fellaster* are rare near the base, together with low–angle tabular cross–beds (facies Cl_1). *Ostrea, Crassostrea* and casts of *Crepidula* are common in the more central parts. In a nearby quarry (R21/763621) at least two silt lenses containing common pholad borings, occur within the limestone. The total thickness of the limestone at these sites is difficult to determine, but appears to be about 10 m. The basal contact is unconformable on loose sandstone of the Okiwa Subgroup (facies S_1), considered to be the sandstone between the Parihauhau and School Shellbeds, with the latter shellbed missing in the aforementioned unconformity.

Rangitatau West Road (Okiwa Trig) section: (Figure 7.3k)

This section contains some of the best exposures of the Kuranui Limestone in the basin. The limestone crops out nearly continuously for about 5 km beside Rangitatau West Road. The limestone itself is best exposed and accessed at the type section at Kuranui Quarry (R22/ 687569) where it unconformably overlies Okiwa Subgroup sandstone (of facies S_2). Here, the limestone is 17 m thick, moderately well cemented, with flaggy cross–beds throughout (facies Cl_1). The lowermost 0.4 m is very fossiliferous, with common *Phialopecten triphooki, Patro* and casts of indeterminate bivalves. *Crassostrea* species are common at the top of this lower part. The main part of the limestone becomes progressively sandier upwards, gradationally passing into fine–medium sandstone with blocky concretionary flags 3–5 cm thick separating sandstone foresets of similar thickness (facies S_7). Cross bedding is most noticeable in the lower 3–4 m of the limestone, becoming less angular in the upper parts. Above the lower 0.4 m, the fauna become less well preserved and diverse, with mainly calcitic species remaining such as *Mesopeplum convexum, Chlamys gemmulata, Phialopecten triphooki, Ostrea, Patro* and *Neothyris*. Internal casts of *Perna* and *Crepidula* are also found, with the latter abundant in the central parts of the limestone. The contact between the Kuranui Limestone and the Upokonui Sandstone is gradual, marked by an increase in sandstone content above the limestone. In this section, the Upokonui Sandstone is 15 m thick, made up of three parts. The lower 2.5 m, is a low-angle cross-bedded well-sorted fine brown sandstone (facies S_5), which is in turn overlain by a 5.5 m-thick flaggy sandstone with 3–5 cm thick flags separating high-angle (>20°) foresets of similar thickness (facies S_7). The upper 7 m consists of trough cross-bedded sandstone, which becomes more massive in the upper 3 m. Fossils in this upper part of the sandstone include *Ostrea, Phialopecten, Mesopeplum, Fellaster* and barnacles (*Balanus*). Other noteable localities in this section are at Okiwa Trig (R22/717598) and below the roadside at R22/695577, where the lower contact of the limestone is marked by a 0.1–0.3 m thick conglomerate of well rounded greywacke pebbles up to 3 cm in diameter channeled into Mangapanian siltstone of facies Z_2.

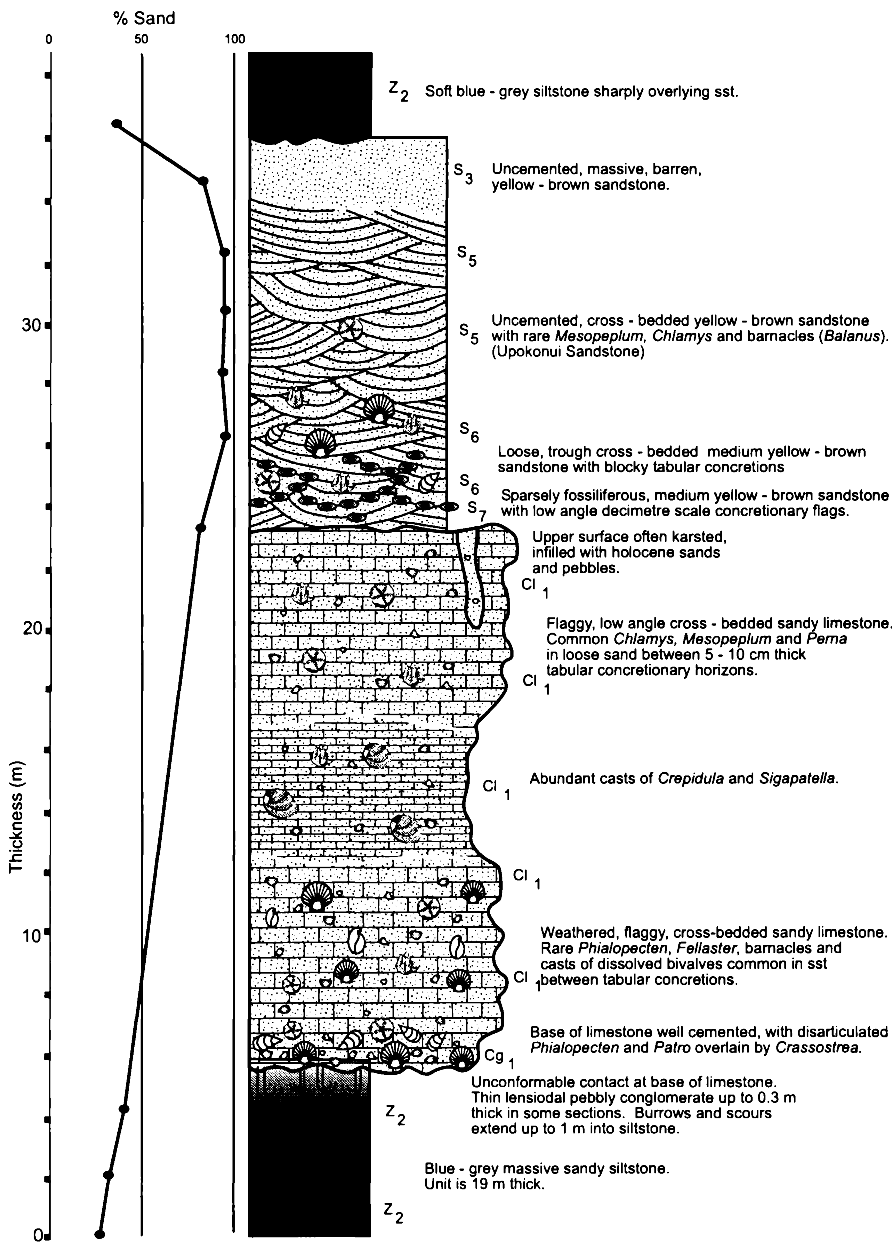


Figure 7.3k: Kuranui Limestone, Windy Point Quarry, Rangitatau West Rd. (Okiwa).

Other sections:

The aforementioned sections have been selected for more detailed examination because of their accessibility. Other less accessible sections were mentioned by Fleming (1953) between the Mangawhero and Parihauhau valleys (Hautawa Shellbed; GS 4204; 4352; 4225). He also mentioned sections within Kuranui Limestone in the Mangaiti and Mangahoropiti valleys and near the mouth of the Waitotara River, none of which were visited in this study. In addition to the sections described above, the Kuranui Limestone was seen cropping out spectacularly in the Kai–Iwi stream at R22/826568, where it is about 12 m thick, showing eastward-prograding large-scale foresets, each foreset being about 1–2 m thick.

Molluscan Paleoecology and Depositional Depth Analysis.

Fossil collections:

The Hautawa Shellbed is one of the most intensely collected shellbeds in the Wanganui Series. In this study data are incorporated from Fleming (1944), Fleming (1953), Carter (1972), Naish & Kamp (1995) and McIntyre & Kamp (1998). Historical lists have been updated to be consistent with that of Beu & Maxwell (1990) and Beu (1995), and are tabulated in Appendix 2. Foraminiferal censuses of the shellbed and adjacent strata in Collen (1972) and Naish & Kamp (1996) are not included.

In collections made in this study, the general position of each molluscan species within the shellbed and overlying siltstone and sandstone are recorded (lower, upper or throughout), as well as the relative abundance and preservation state. Each species is subdivided into three fairly arbitrary semi-quantitative ranges; abundant (>15%), common (5-15%) and rare (<5%). Specimens identified in the field that could not be collected are included, but are indicated as field identifications only. For example, in the Kuranui Limestone at Wairangi Station, *Phialopecten* sp. u-r (f) means that the species is rare in the upper part, but is a field identification only and has not been collected.

To estimate the paleodepth range in which the shellbed was deposited in various locations across the basin, the faunal lists for the shellbed within each section were collated into a master list, and most extinct genera and species were removed from the list. From the remaining list of extant species, eurybathyal species and those with unknown depth ranges were removed until only extant species with relatively accurate depth ranges remained. These remaining species and their depth ranges were plotted against depth on a floating bar graph. The overlap between the greatest depth of *in situ* shoreface species and the shallowest occurrence of deeper-water species reveals the likely depth range inhabited by the assemblage. Depth ranges have been collated from Powell (1979), Beu & Maxwell (1990) and Morley & Hayward, (in prep). Where possible, depth ranges assigned to the extant species reflect both living and dead specimens. In some cases extinct species have been assigned depth ranges. This is done only when the extinct species is closely related and taxonomically similar to an extant species belonging to the same genus. Examples of this include substitution of the depth ranges of the extant gastropod *Pelicaria vermis* to the extinct *Pelicaria* n.sp. aff. *zelandiae*, *Tawera spissa* for *Tawera subsulcata,* and *Zethalia zelandica* for *Zethalia coronata*. While some error is expected in the maximum depth range of nearshore species because of downslope reworking, and the range must be regarded as a maximum, the death assemblages are generally considered to be an accurate representation of the depositional environment and depth (e.g. Hallam, 1967; Springer & Flessa, 1996; Olivera & Wood, 1997; Kidwell, in press). Depositional paleodepth estimates for the Tuha Siltstone and Upokonui Sandstone using molluscs are also attempted, but the lack of faunal concentration and diversity in these units means that depth assessments are less quantitative than those assigned to the shellbed.

Many of the difficulties outlined in Beu & Maxwell (1990, p.17) normally associated with determining paleodepths from fossil molluscs are reduced in this study because the depth of deposition is inferred using the depth ranges of extant species, and to a lesser extent, congeneric forms of extant molluscs. No depth range data derived from molluscs living outside the New Zealand region were used in this study.

Distribution of Fossils:

Figure 7.4 shows the distribution of the bathymetrically useful subset of molluscs across the outcrop belt of the Hautawa Shellbed. Shallow-water species are more common in the western parts, with shoreface taxa such as *Perna, Divaricella* and *Fellaster* common and abundant in the Kuranui Limestone, and also found in the lower, sandy part of the Hautawa Shellbed. These shallow-water taxa are not as common in the upper part of the shellbed as lower down, indicating that the lower and upper parts represent different depositional environments. In the more central parts of the basin, the molluscs *Neilo, Pratulum* and *Antalis* are found near the top of the shellbed. The preferred habitat of these molluscs is within relatively fine sediment, which matches a generally eastwards–deepening trend in the paleodepth of the shellbed between the coast and the Ruahine Ranges. The faunal diversity in the upper parts of the shellbed is considerably less than in the lower parts; this also suggests a greater depth of deposition than in the lower parts (e.g. Morton & Miller, 1968). However, it could be argued that this lessening of diversity is more controlled by the nature of the substrate than by water depth. Fossils from the Tuha Siltstone and Upokonui Sandstone are not plotted on this figure.

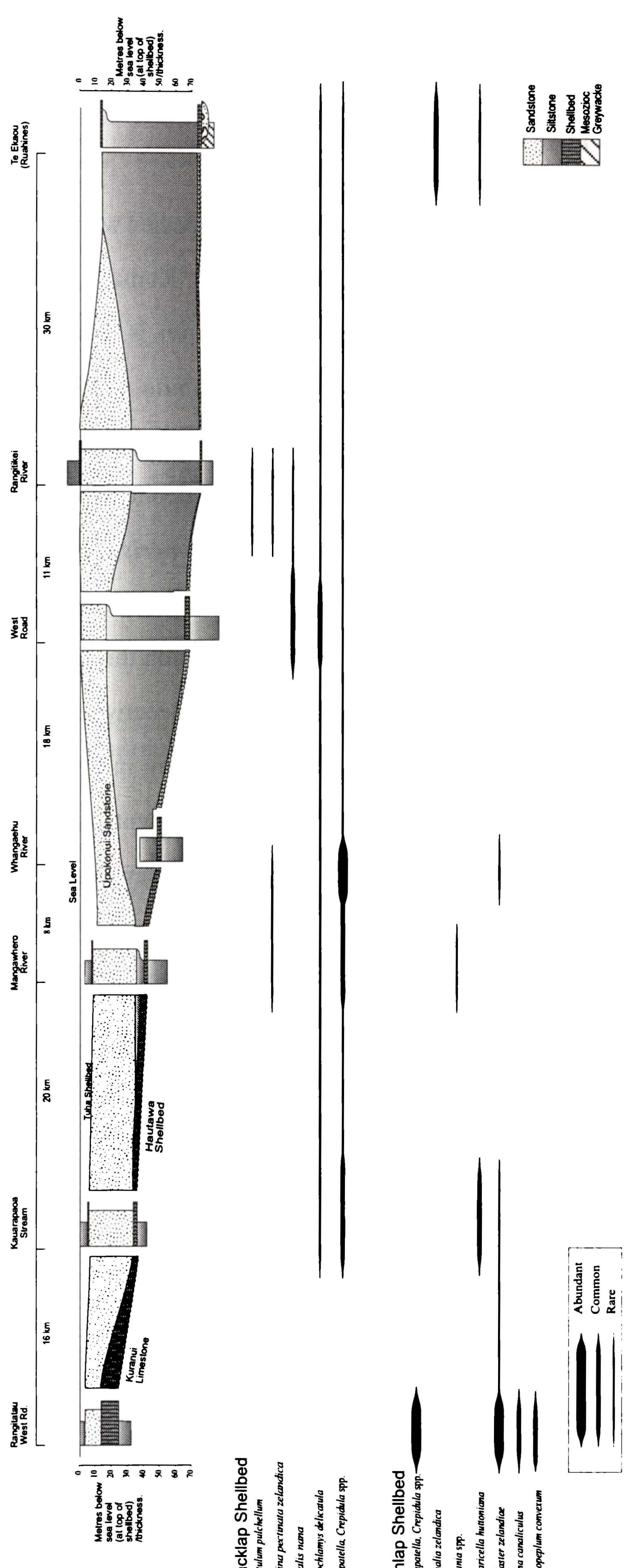


Figure 7.4: General facies and distribution of bathymetrically useful macrofauna, Hautawa Shellbed. The faunal data relates only to the Hautawa Shellbed, near the base of the columns.

Depositional Depth Anlaysis.

Pohangina valley: (Figure 7.5a)

The depth ranges of extant species (and extinct species with inferred depth ranges) found in the Hautawa Shellbed in the Te Ekaou Stream at Komako, Pohangina valley are shown in figure 7.5a. The minimum possible water depth is inferred to be 0 m, based on the occurrence of the extremely shallow species *Zethalia coronata, Haliotis, Dosinia subrosea* and *Divaricella huttoniana.* The maximum water depth is estimated to be in the range of 40–70 m, which is the overlap of the shallowest depth at which *Fissidentalium zelandicum* is found (40 m), and the maximum depth of *Glycimeris waipipiensis* (70 m, using the depth range of modern *G. modesta*), both of which occur in the upper part of the shellbed. In addition, the gastropod *Pelicaria convexa* is common throughout the siltstone overlying the shellbed, consistent with an offshore mid-shelf paleoenvironment (Beu & Maxwell, 1990). Significantly, the Upokonui Sandstone is not present in this section, which means that the water depth did not regress to a shoreface enviroment during the subsequent fall in sea-level. The offshore gastropod *Pelicaria convexa* occurs throughout the siltstone and is also present in the Tuha Shellbed, which conformably overlies the siltstone. Thus an estimate of the overall oscillation of relative water depth for this succession at this locality is 0 m at the base of the conglomerate, rising to 55 m at the peak of inundation near the top of the conglomerate, before falling to ~ 20 m at the top of the siltstone.

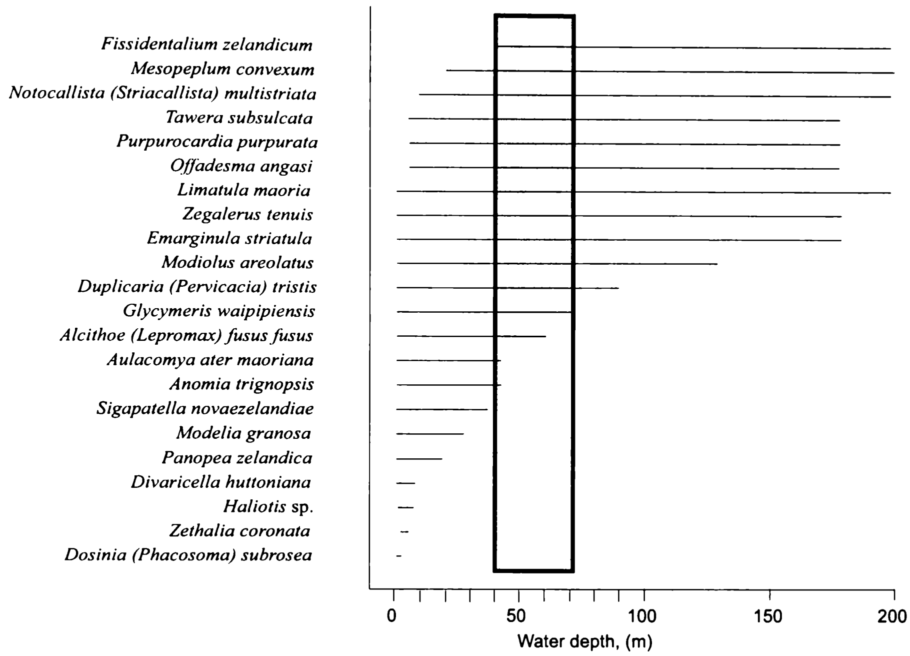


Figure 7.5a: Depth ranges of selected species, Hautawa Shellbed at Komako, Pohangina valley. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Rangitikei River valley: (Figure 7.5b)

Species used for determining the paleobathymetry of the Hautawa Shellbed in the Rangitikei River valley section are plotted in figure 7.5b. One point of note here is that there are no extremely shallow-water species in the shellbed at this locality, suggesting that perhaps the paleoshoreline is not preserved in the shellbed at this location. This inference is supported by the occurrence of a number of typical inner–mid shelf fauna such as *Paracomitas, Pratulum* and *Antalis.* From the depth plot, the absence of extremely shallow water species indicates that the shallowest depth was as much as 20 m, a depth consistent with the conformable base of the unit. A maximum water depth of between 30 and 60 m at the top of the shellbed is taken from the overlap of the typical shoreward extent of *Paracomitas protransenna* (30 m) and the basinward extent of *Ostrea* (60 m). However, the lack of diversity in this shellbed means that confidence in assesment of the depth ranges is less than in other sections. Above the shellbed, the occurrence of *Amygdalum* and *Pratulum* in the siltstone indicates a typical mid–shelf, quiescent, terrigenous-dominated depositional environment (Naish & Kamp, 1995). The occurrence of *Panopea* in the upper parts of the siltstone and sandstone combined with the unconformable contact between the Upokonui Sandstone and Tuha Shellbed, indicates a return to inner shelf, higher-energy conditions, with water depths probably less than 15 m. Thus the total change in bathymetry for this succession derived from faunal and stratigraphic evidence is 20 m at the base of the Hautawa Shellbed, rising to 30–60 m at the peak of flooding at the top of the shellbed, regressing to 10 m at the top of the Upokonui Sandstone.

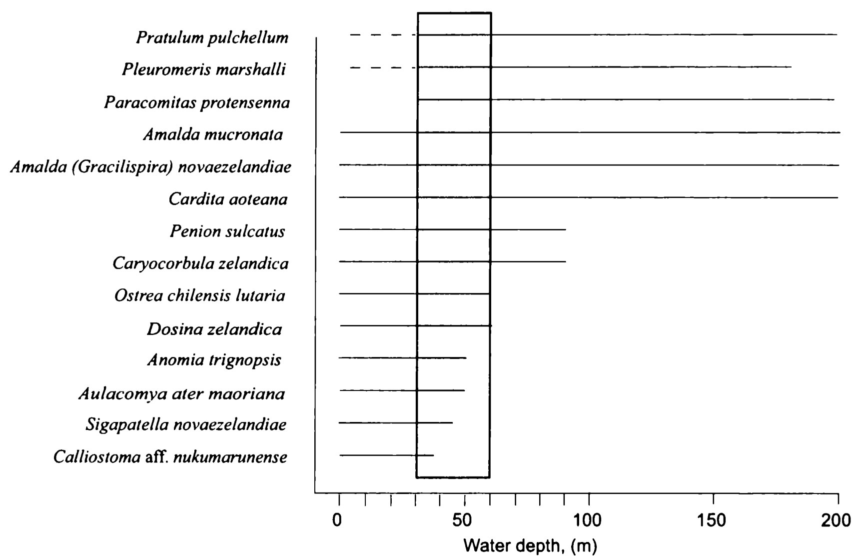


Figure 7.5b: Depth ranges of selected species, Hautawa Shellbed, Rangitikiei River. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Hautawa / Watershed Road sections: (Figure 7.5c)

The depth range of fossil molluscs occurring in the Hautawa Shellbed in both of these sections is shown in figure 7.5c. These sections are 4 km apart, but are treated as one site here to give a better representation of the faunal diversity of the area and hence the accuracy of the paleodepth estimate. As with the Rangitikei River section, species consistent with a sandy shoreface environment are rare, the only possibilities being the infaunal bivalves *Zenatia* and *Oxyperas*. However, the variably conformable - unconformable base to the shellbed, and the occurrence of these bivalves indicate a minimum depth between ~ 5 to 15 m for the base of the unit. The maximum depth of deposition is taken to be the overlap between the maximum depth of *Perna* (50 m) and the maximum depth of *Alcithoe arabica* (70 m), found *in situ* at the top of the shellbed in the Watershed Road section. The Tuha Siltstone and Upokonui Sandstone were not examined in this section.

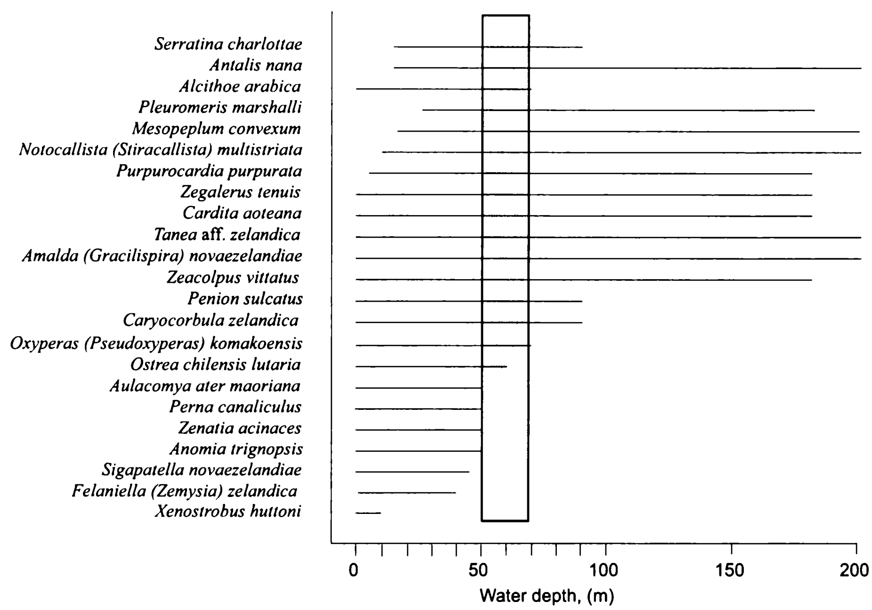


Figure 7.5c: Depth ranges of selected species, Hautawa Shellbed in Watershed and West Road sections. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Whangaehu River valley: (Figure 7.5d)

Selected depth ranges of fossil molluscs for the Hautawa Shellbed in the Whangaehu River valley at Mangamahu are illustrated in figure 7.5d. The faunal assemblage within the shellbed in this section is very similar to its correlative at the type section (West Road), with comparatively few shallow-water species found, the exceptions being the infaunal bivalves *Myadora striata* and *Panopea zelandica.* The base of the shellbed is unconformable at this site, and together with the occurrence of these species gives an estimated minimum paleodepth of between 0–10 m. The maximum water depth at the top of the shellbed is taken as the overlap between the maximum shoreward extent of *Monodilepas monilifera* (30 m) and the maximum depth occurrence of *Perna* (50 m), both of which have been collected from the uppermost parts of the shellbed in this section. The faunal assemblage of the thin shell horizon in the Tuha Siltstone indicates that it was deposited in shallower water than the Hautawa Shellbed, at a depth of around 15–40 m (depth range overlap of *Antalis* and *Splendrillia*). This suggests that the siltstone represents a progressively upwards-shoaling succession from a maximum depth of around 40 m at the base to about 20 m in its central parts, an assumption that is consistent with the slight increase in grain size up through the siltstone. Without any information on depth of deposition from the Upokonui Sandstone in this section, the total rise and fall of sea–level for this cyclothem is incomplete, but all of the sea–level rise, and the early part of the fall can be represented with the relative depth ranges varying from ~ 5 m at the base of the shellbed, deepening to 40 m in the base of the Tuha Siltstone, and regressing to less than 20 m near the top of the siltstone (the uppermost unit of the succession observed in this section).

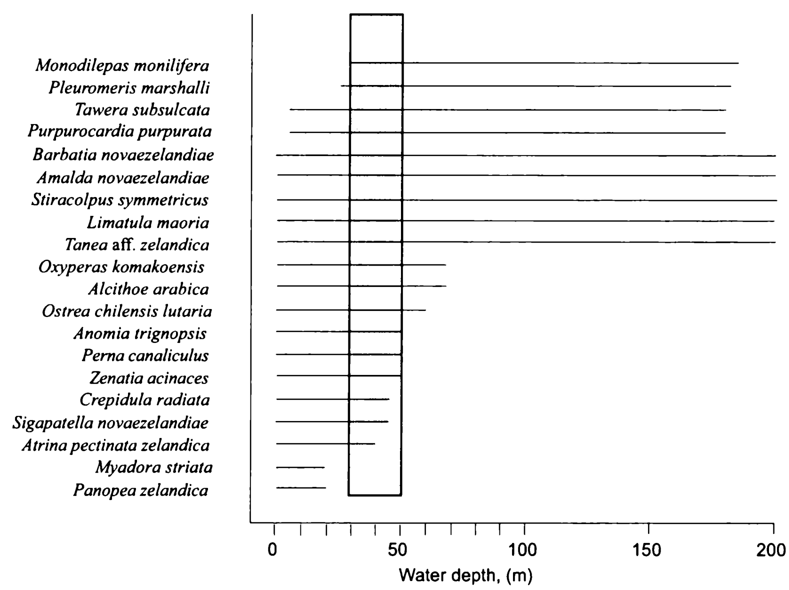


Figure 7.5d: Depth ranges of selected species, Hautawa Shellbed at Mangamahu, Whangaehu River valley. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Mangawhero River valley: (Figure 7.5e)

The likely depth ranges of fossils identified in the Hautawa Shellbed in the Mangawhero River valley are shown in figure 7.5e. The occurrence of the shallow-water bivalves *Dosinia subrosea, Barnea similis* and *Myadora striata* suggests a minimum water depth of

0 m, which is consistent with the wave–cut unconformity at the base of the shellbed. The maximum depositional depth of the shellbed is bracketed by the shallowest limit of *Mesopeplum convexum* (20 m) and the deepest point at which *Crepidula radiata* and *Sigapatella novaezelandiae* (both 45 m) occur on the modern shelf. The top of the Upokonui Sandstone was not accessed in this section. To gain information about the depositional depth of this unit, data is substituted from the section at Parihauhau Road. In that section, the Upokonui Sandstone contains common *Fellaster* in its upper parts, and also, the Tuha Sandstone rests unconformably above it. These factors provide evidence for an extremely shallow shoreface depositional environment, with a minimum depth of 0 m at the upper contact of the sandstone with the Tuha Shellbed.

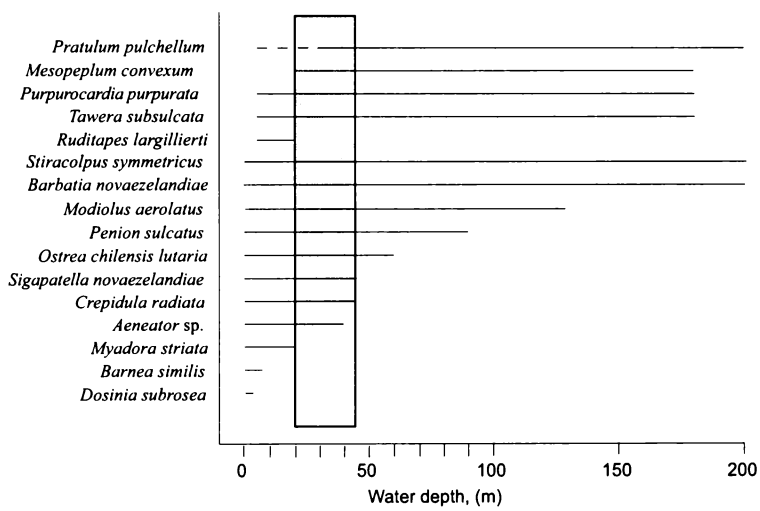


Figure 7.5e: Depth ranges of selected species, Hautawa Shellbed in Mangawhero river valley. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Kauarapaoa valley: (Figure 7.5f)

Figure 7.5f displays the likely depth ranges of key fossils collected from the Hautawa Shellbed in the Kauarapaoa valley. Here, the faunal diversity in the depth plot is relatively low, which is the result of less comprehensive collecting from the shellbed in this section, and not necessarily of a lack of molluscan diversity in the shellbed itself. However, the extant species plotted here are sufficient to estimate the likely depositional depth ranges. The presence of the echinoid *Fellaster zelandiae* and the extremely shallow-water bivalves *Divaricella huttoniana* and *Myadora striata* immediately above the unconformable base to the unit means that the shallowest depth the shellbed was deposited in is 0 m. The maximum water depth at the top of the shellbed is inferred to lie within the 20 - 45 m range, estimated from the shallowest occurrence of the scallop *Mesopeplum convexum* (20 m) and the maximum depth of the limpet - like gastropods *Sigapatella* and *Crepidula* (both 45 m). In the uppermost parts of the Upokonui Sandstone, the presence of *Fellaster* and *Mylitella* signal a return to extremely shallow, high-energy shoreface conditions, also indicated by the medium sandstone texture of the Upokonui Sandstone. Furthermore, the sharp unconformity between the sandstone and the Tuha Shellbed (interpreted here as a wave–cut surface) is consistent with extremely shallow conditions. Thus, the overall change in amplitude of relative sea–level derived from the fauna in this succession is estimated at 0 m for the base of the Hautawa Shellbed, deepening to ~ 35 at the top of the shellbed, regressing to 0 m at the upper contact of the Upokonui Sandstone.

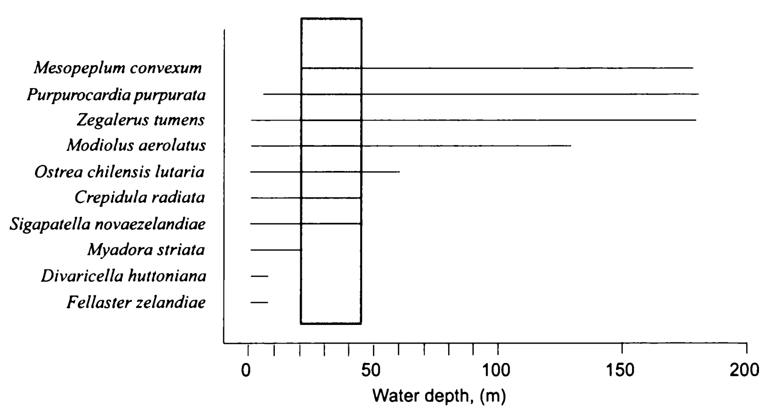


Figure 7.5f: Depth ranges of selected species, Hautawa Shellbed in Kaurapaoa valley. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Rangitatau West Road, Okiwa (Kuranui Limestone): (Figure 7.5g)

The faunal diversity within the Kuranui Limestone at Rangitatau West Road is low because significant carbonate dissolution has taken place, presumably dissolving many aragonitic taxa. In addition, difficulties in collecting specimens from this well cemented unit means that comparatively few extant species can be used to construct a depth range graph. The depth ranges of the eight extant species that were collected are plotted in figure 7.5g, with the likely maximum water depth also shown within the shaded area. The unconformable, conglomeratic base to the unit and the occurrence of *Fellaster zelandiae* near its base indicates a minimum water depth of 0 m in the lowermost parts. It is likely that many of the typically shallow-water aragonitic bivalves normally expected in this high-energy, sandy environment are no longer present in the limestone due to excessive dissolution. The maximum depositional depth inferred for the limestone is taken as the overlap between the shoreward extent of *Mesopeplum convexum* (20 m), and the maximum depth at which *Perna, Crepidula* and *Sigapatella* occur (45 m) as all of these are common in the upper part of the limestone. However, the cross-bedding visible throughout the limestone suggests that a maximum depositional depth in the shallow end of this 20-45 m range is more likely, being more proximal to a high-energy environment. Fossils within the Upokonui Sandstone are reworked, so depth estimates cannot be precise, an observation emphasised by the multiple occurrences of *Mesopeplum, Fellaster* and barnacles (*Balanus*) within the upper part of the unit. However, the facies and faunal characteristics of the upper part of the sandstone strongly indicate close proximity to a paleoshoreline, and together with the unconformable contact between the Upokonui Sandstone and the overlying siltstone, a paleodepth approaching 0 m is estimated for the top of the sandstone. Therefore, an overall paleodepth change for this succession is 0 m at the unconformable base of the limestone, deepening to about 25 m at the Kuranui Limestone / Upokonui Sandstone contact, then shallowing to 0 m at the top of the Upokonui Sandstone.

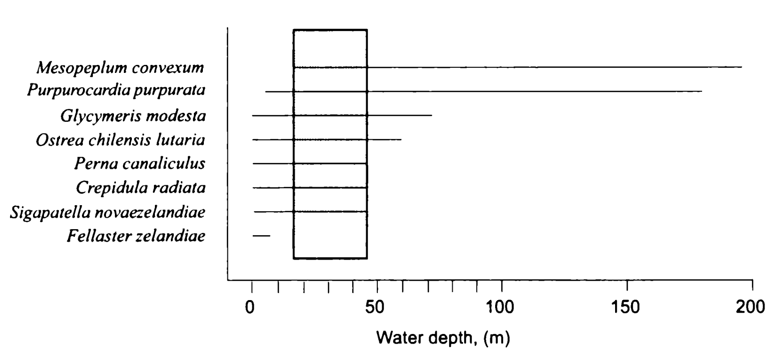


Figure 7.5g: Depth ranges of selected species, Hautawa Shellbed at Okiwa, Rangitatau West Road. Shaded areas represent the likely maximum water depth range indicated by the fauna.

Facies Trends.

Variations in the thickness, grainsize and structure of the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone reveal patterns consistent with both the paleodepths indicated from macrofaunal assemblages, and an eastward-deepening shoreline to basin profile. In the western Wanganui Basin, the occurrence of shallow-water species within the Hautawa Shellbed is matched with an increase of grainsize in the shellbed matrix (from siltstone to sandstone to gravelly sandstone in the Upokonui Sandstone) and also a thickening of the unit from 0.5 m (Rangitikei River) to 17 m (Kuranui Limestone, Rangitatau West Rd.). Furthermore, the amount of faunal reworking within the shellbed increases to the west. Throughout the Hautawa Shellbed in Rangitikei River valley, all the species appear to be near-in *situ,* and set in a siltstone matrix (facies Cz_2). In the adjacent western section (Watershed Rd.) the lowermost part of the shellbed contains clearly reworked fossils in a sandstone matrix (facies Cs_1 beneath Cz_2). The shellbed matrix becomes progressively sandier to the west, with sand gradually replacing silt from the base to the top of the unit, until the matrix is entirely sandstone, tabular cross-bedded throughout, and all fossils are reworked (facies Cl_1, Kuranui Limestone, Rangitatau West Rd.). The Basal and Glycymerid Conglomerates in the Te Ekaou Stream section, Pohangina valley, are unique facies not observed elsewhere in the basal Nukumaruan succession in Wanganui Basin. The large greywacke cobble / pebble clasts forming the matrix of the unit in which the fauna occur (facies Cg_1, Cg_2) are consistent with the rocky shoreface molluscan faunal assemblages collected from these units. The Te Ekaou Stream section is considered to have been deposited near a southeastern shoreline of the basin where basement was been exposed prior to the rapid subsidence and sedimentation occurring at this locality. The fining-upwards transition from cobbles to pebbles mirrors the change from sandstone-siltstone matrix upwards within the Hautawa Shellbed, which is inferred to represent transgressive deepening during deposition. Therefore, the succession of carbonate facies from shallowest (rocky shoreface) to deepest (mid-shelf) here is: Cg_1, Cg_2, Cl_1, Cs_1, Cz_1, Cz_2, Cz_3 (see Table 7.2 for explanation of facies codes).

The siliciclastic units (Tuha Siltstone and Upokonui Sandstone) above the Hautawa Shellbed / Kuranui Limestone / Te Ekaou Conglomerates also show definite lateral facies variation. The Tuha Siltstone is thickest in the Te Ekaou Stream section (58 m thick) and progressively thins westward to the Parihauhau Road section, wedging out between the Hautawa Shellbed and Upokonui Sandstone between the Parihauhau and Wanganui valleys. Furthermore, the siltstone is slightly coarser west of Mangawhero valley (facies Z_2) compared with its equivalent to the east of this section, where the dominant facies is a massive siltstone (facies Z_1). Lack of bedding features within the Tuha Siltstone preclude further facies analysis beyond the thickness and grainsize parameters, but these features provide sufficient evidence for an eastward-deepening, inner to mid-shelf depositional environment. Conversely, the Upokonui Sandstone reaches its greatest thickness in the Parihauhau valley section (47 m thick) and thins both eastward and westward from this locality. To the east of this section, the Upokonui Sandstone thins to 32 m in the Rangitikei River valley, before disappearing from the sequence between this section and the Te Ekaou Stream section. The absence of the Upokonui Sandstone in the Te Ekaou Stream section is further evidence of an eastward deepening, with the upper part of the Tuha Siltstone considered to be coeval with the Upokonui Sandstone. West of Parihauhau valley, the Upokonui Sandstone also becomes thinner and more cross-bedded, which demonstrates a shallowing and progressive loss of accommodation in that direction.

The facies within each of the units investigated in this study show a clear eastwards deepening trend. The similarity in interpretation of the faunal and other facies parameters is shown in figure 7.4, where the occurrence of depth-diagnostic species within the shellbed are matched by facies analysis of both the shellbed and the overlying terrigenous units to demonstrate the positioning of these facies on the contemporary shelf. A point of interest is that the extremely shallow-water marine conglomerates (Hautawa Shellbed equivalent) at the base of the Nukumaruan succession in the Te Ekaou Stream section are overlain by the greatest thickness of Tuha Siltstone in the basin. This implies accelerated tectonic deepening at this locality during early Nukumaruan time. Prior to the deposition of the conglomerates, the basin axis lay to the northwest, probably between this locality and the Rangitikei River section. During the late stages of the conglomerate deposition, the depocentre migrated southwards, creating more accommodation for the accumulation of the Tuha Siltstone.

Paleodepth trends:

In the preceding section, the changes in water depths at key sites across the basin have been estimated chiefly from the macrofauna. Figure 7.6 illustrates the total rise and fall of sea-level estimated for each section, using a common depth scale. In this figure, each bell-shaped curve illustrates the increase (left side of curve) and subsequent decrease in depth of deposition. There are three main points of interest on these curves. The first is the depth at the base of the shellbed, marking the water depth at each locality at the beginning of the transgression. The second is the maximum flooding depth at the apex of the curve, a point that corresponds to the top of the shellbed. The endpoint of the curve (lower right) marks the shallowest water depth estimated for the top of the sandstone, or the surplus accommodation at each locality during the sea-level minimum at the end of the regressive phase. Thus, each curve plotted here records the observed change in paleobathymetry through the sequence. The points on the curves are plotted at the mean depth of the estimated range from macrofossils. However, most of the water depth estimates are ranges, so this range is plotted as error bars, within which the paleodepth probably lay. Broad zones marking the water depth at the base of the cyclothem, the maximum flooding and immediately below the upper sequence boundary are shown on figure 7.6.

At the beginning of the transgression water depth was at a maximum in the vicinity of the Rangitikei River section, which was submerged 15-25 m. The seabed shallowed to the west, coinciding with the base of wave-generated erosion in the area between the Whangaehu and Mangawhero River valleys. The decrease to the west in the amount of increase of water depth, together with the occurrence of an erosional contact at the base of the shellbed indicates that the shoreline transgressed to the west. The highstand shoreline was probably situated on the Patea-Tongataporutu High. In the easternmost section (Pohangina valley), the initial depth was near 0 m, as demonstrated by the obvious onlap onto the greywacke basement. This is interpreted as representing the *southern* shoreline, and the earliest (late Pliocene) generation of accommodation at this locality in response to southward migration of the basin depocentre.

The maximum water depth at the top of the shellbed decreased from 50-60 m in the vicinity of the Turakina - Rangitikei watershed, to an estimated 20-30 m at Okiwa in the west.

The difference between the initial and maximum water depth in the Rangitikei River valley (~ 40 m) is an estimate of the eustatic rise in sea-level in the first half of this cycle; the subsequent fall may have been greater at 40-70 m. The decrease in the observed increase in water depth in sections towards the west (Figure 7.5) reflects the transgression in that direction.

It is possible that the maximum flooding did not occur at the top of the shellbed, but could lie within the base of the siltstone, possibly within the lower 5 m or so of the unit. This has been overcome by including fossils from the lower part of the siltstone to the depth plot to estimate the maximum depth range, which is the parameter required here. An example of this is in the West / Watershed road sections, where species from the base of the siltstone are included, and the maximum depth range is estimated to have been 50–70 m. The nearby Rangitikei River section depth plot only includes species from the shellbed, and the maximum depth range estimate is shallower than at West Road (40–70 m), when it would be expected to be at least as deep as that of the West and Watershed Road sections.

The return to shallow-water depths of deposition at the top of the sandstone is also illustrated in figure 7.6. Predictably, this also shows an eastward-deepening trend, with the exact seaward limit of wave–base erosion not well located on the ground, but occurring between the Rangitikei and Mangawhero River valleys. Thus, the surplus accommodation at the end of the regression became greater to the east, being about 20 m in the vicinity of the Pohangina valley. The difference between the paleobathymetry at the end of the cycle at Rangitikei valley versus Te Ekaou Creek (Pohangina valley) results from greater tectonic subsidence at the latter locality, reflecting the southward migration of the depocentre.

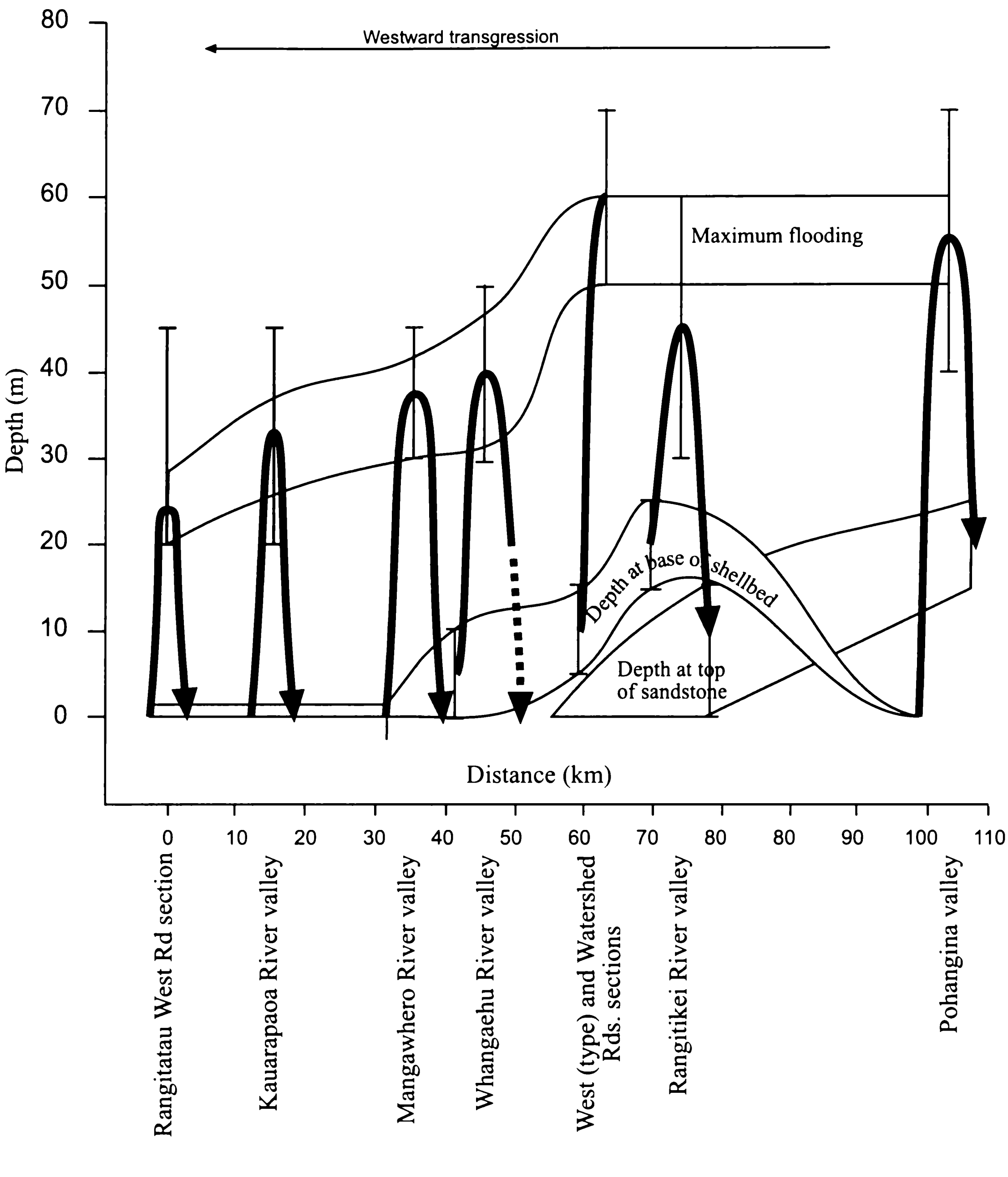


Figure 7.6: Magnitude of sea - level oscillations for cycle containing Hautawa Shellbed at selected locations from west-east across the basin. The likely magnitude of the relative sea-level rise and fall determined by paleobathymetric analysis of the fauna within the shellbed at each locality is marked by the rise (transgression) and fall (regression) of the thick arrows. The three grey bands each illustrate the likely bathymetry at the start, middle and end of the cycle at each of these localities. The top of the Hautawa Shellbed is coeval with the apex of each of the thick lines, and the top of the Upokonui Sandstone equates to the return of the arrowheads to 20-0 m water depth.

Sequence Stratigraphic Interpretation.

Previous sequence stratigraphic studies of Wanganui Basin cyclothems place each of the three main facies groups into separate systems tracts (e.g. Naish & Kamp, 1997). Hence the shellbeds have been ascribed to the Transgressive Systems Tract (TST), the siltstone units to a Highstand Systems Tracts (HST), and the sandstone units to the Regressive Systems Tracts (RST) (e.g. Abbot & Carter, 1994; Naish & Kamp, 1997; Kamp & McIntyre, 1999). This rationale is explained in some detail in Naish & Kamp (1997), together with further refinement of shellbed types found within each of these systems tracts. However, all of these studies have been one-dimensional, with no attempt or opportunity to map out the systems tracts across the related paleoshelf due to lack of exposure generally in the downdip / paleoslope direction. The question then arises as to how the systems tract boundaries relate to facies boundaries; that is, do the lithological boundaries parallel the system tract boundaries across the paleoshelf, as implied by the earlier studies, or do the lithological boundaries cut across the systems tract boundaries? The following sections argue, based on the Hautawa cycle, that the boundary between the siltstone and sandstone actually cuts across the HST and RST systems tract boundaries, as shown in figure 7.8. This means that without first reconstructing the paleobathymetry and paleogeography for a sequence it is not possible to place the position of the HST-RST boundary in a section.

Transgressive systems tract:

The transgressive systems tract (TST) refers to those sediments onlapping the transgressive surface, and extending upward to the downlap surface. As a significant increase in depth has been demonstrated within the Hautawa Shellbed, it clearly lies within the transgressive systems tract. In the more western sections the base of the shellbed / limestone is unconformable. This contact is taken as the sequence boundary, but it probably formed as a ravinement surface or transgressive surface of erosion (TSE). In sections to the east where this contact is conformable, the base of the TST is also placed at the base of the shellbed because it marks the start of onlap, the shellbed forming as a response to a decrease in terrigenous sediment flux probably because the sediment accumulated in back-stepping shoreface deposits.

The top of the TST probably coincides with the top of the shellbed in each of the sections, although in a more seaward (eastward) direction it could lie slightly above the shellbed, as predicted by Carter *et al.* (1998). However, as previously stated the maximum water depth probably occurs in the lower part of the siltstone above the shellbed. Therefore not all of the transgression is contained within the shellbed, the shellbed only being deposited during the most rapid part of the sea–level rise.

Highstand systems tract:

The term highstand systems tract (HST) is applied to those sediments deposited during the late part of a relative sea–level rise, a relative stillstand, and the early part of a relative fall (Van Wagoner *et al.*, 1988). In this situation, the siltstone unit is placed within the HST, with the downlap surface marking the physical surface between the two systems tracts. As mentioned above, in parts of the basin the maximum flooding surface will lie in the base of the siltstone.

In the western sections where the siltstone is not present, lack of fossils in the sandstone above the limestone precludes determination of the level of maximum flooding, but it is inferred to lie either at the top of the limestone, or very slightly above the limestone in the Upokonui Sandstone. The top of the HST is less well defined, but probably comprises *all* of the Upokonui Sandstone above the Kuranui Limestone; further east the Upokonui Sandstone fines to a siltstone (Tuha Siltstone), as shown in figure 7.7.

Regressive systems tract:

The regressive systems tract (RST) refers to those sediments deposited during the middle stages of regression, when the rate of relative fall in sea-level exceeds the rate of basin subsidence, and accommodation is progressively reduced (Naish & Kamp, 1997). Therefore, strata near the top of the sequence can be included in this systems tract. In the case of the cyclothem containing the Hautawa Shellbed, an RST cannot occur in the westernmost sections, because RSTs form under falling sea-level conditions, and no accommodation is available in the vicinity of the HST shoreline.

Thus, as described above, the Upokonui Sandstone in the western part of the study area is interpreted as an HST deposit. However, an RST will have been present in the mid to outer paleoshelf environment. This suggests that the HST / RST boundary, which is a time-line, must pass across the facies boundary, in a fashion shown in figure 7.7. The deposition of the siltstone / sandstone as coinciding with the HST / RST boundary probably occurs somewhere between the West Road and Rangitikei River. Further into the basin, the RST is probably represented by progressively finer-grained sediment to the east, and in the Pohangina valley cannot be exactly located in the stratigraphy being indiscernible from, but stratigraphically above, HST siltstone.

The general positions of the systems tracts are shown in figure 7.7, which illustrates how systems tract boundaries are not always parallel with facies boundaries. This is anticipated by Walthers Law of facies – which states that facies occurring within a conformable succession are formed in laterally adjacent environments. Therefore, each systems tract indeed comprises a linkage of contemporaneous depositional systems (Van Wagoner *et al.*, 1988) containing a basinward progression of lithofacies. This is pronounced in the HST and RST, but not in the TST, which is carbonate-dominated in this sequence.

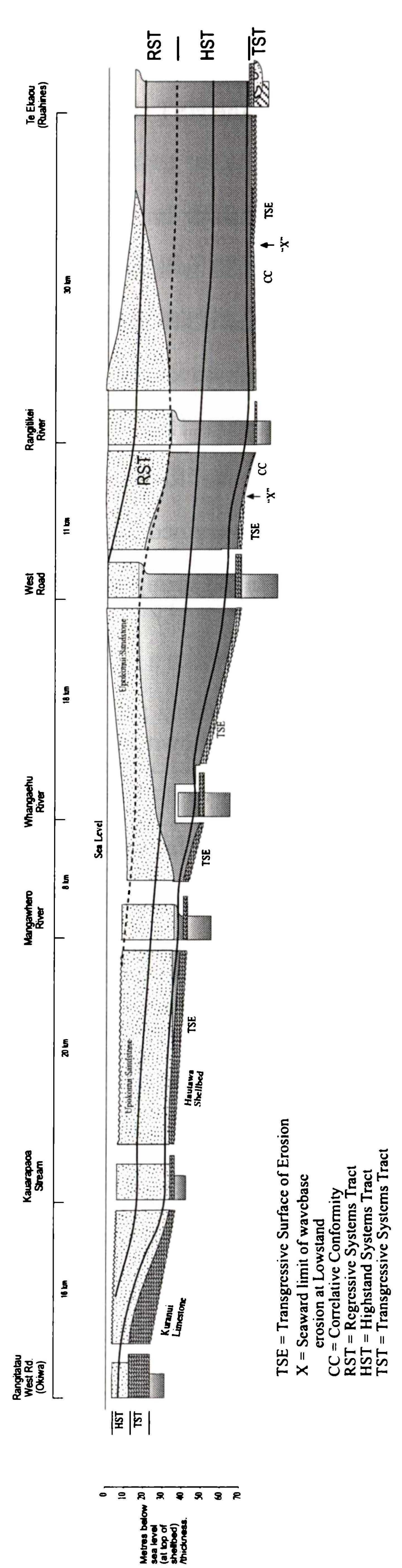


Figure 7.7: Sequence stratigraphic interpretation of Whariki Formation. General pattern of isochrons is marked by bold lines, and dashed isochron marks HST / RST boundary.

Discussion.

The bioevents marking the Mangapanian / Nukumaruan boundary, coincident with the base of the Hautawa Shellbed, not only facilitate correlation of the unit between sections, but also provide information on the late Cenozoic climatic deterioration. The abrupt extinction of warm-water taxa (e.g. *Crassotrea ingens, Maoricardium, Polinices, Phialopecten thomsoni*) and the arrival of subantarctic taxa in the shellbed (chiefly the scallop *Zygoclamys delicatula*) record the northward incursion of an Australasian Subantarctic watermass (ASW) to this latitude at this time, probably via the Mernoo Saddle on the Chatham Rise (Nelson *et al.*, 2000). This incursion of subantarctic waters was possibly associated with the concurrent increase in Northern Hemisphere glaciation. The occurrence of the cold-water fauna in the shellbed did not necessarily mark the *onset* of glaciation, but merely the arrival of subantarctic surface waters carrying viable cold water larvae to this latitude. This hypothesis is supported by several factors. The first is the occurrence of *Zygochlamys delicatula* in the South Island (North Canterbury) and southern North Island (southern Wairarapa) in possibly Mangapanian strata (Beu, 1969; Beu & Maxwell, 1990), which may be a record of the early stages of the northern advance of subantarctic waters, with *Zygochlamys delicatula* being found in a northward thinning "*Delicatula* Ecozone" of which the Hautawa Shellbed forms one of the northernmost and shortest-lived occurrences (Beu, 1969). Secondly, species in the base of the Hautawa Shellbed in Wanganui Basin that are otherwise limited to Mangapanian and older rocks record the final stages of the northern retreat of these warm–water species, as subantarctic waters approached and eventually transgressed this latitude (between 39° and 40° North) during deposition of the shellbed. Thirdly, *Zygochlamys delicatula* has been found only in the lowermost three Nukumaruan coquinas in Wanganui Basin - Hautawa Shellbed, Tuha Shellbed and Piripiri Limestone (Carter, 1972), and is rare in the latter two units. This means that the presence of subantarctic waters at these latitudes was brief (OIS 88-84), consistent with the view that an incursion or incursions of these cold waters are more likely to have occurred than a sustained establishment of the Subtropical convergence at a more northerly latitude than its current position during the late Pliocene.

The opportunity afforded by the outcrop of these three units across the width of the basin demonstrates the nature of a cyclothem across part of its paleoshelf, and how systems tracts can be applied in a two-dimensional sense to strata in outcrop. The approach taken here of looking at one cyclothem only to establish facies trends across the shelf differs from that of Saul *et al.* (1999) who created seven cyclothem motifs in an attempt to classify the various styles of cyclothemic expression found in the basin. The seven types of motif are (presumably) based on actual outcrops within the Nukumaruan / Castlecliffian rocks, and each corresponds to a relative position on a conceptual, but non-existent paleoshelf. Application of this motif approach to the cyclothem studied here is possible to a limited extent, but not all of the strata in the above localities can be classified by this method because of subtleties in facies. The only sections in this study that rigorously conform to the motif classification approach are those in the Whangaehu and Turakina valleys. This is not surprising, as the motif approach is simply an array of discrete, unrelated cyclothems, which are constrained neither by time nor space. However, the two-dimensional nature of the cyclothem comprising the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone reveals a cross-shelf pattern of facies and systems tract distributions that is constrained by both time and space, and therefore provides a more accurate, real, tangible example of how the sequence architecture changes across a paleoshelf. An example of how a study involving adjacent sections of coeval strata can improve the accuracy of the sequence stratigraphic interpretation can be seen in other studies involving this sequence (Kamp & McIntyre, 1998). Interpretation of the Whariki Formation in the Wanganui River section at Parikino was difficult because only two units are present, the Hautawa Shellbed and Upokonui Sandstone. That interpretation placed the lower part of the Hautawa Shellbed in the TST, the upper part of the Hautawa Shellbed in the HST, and the Upokonui Sandstone in the RST. The present study has shown that this interpretation is not correct, and the revised sequence stratigraphiy ishows that the Hautawa Shellbed comprises the TST, and is overlain by the Upokonui Sandstone, which represents the HST. There is no RST in the sequence at this locality.

While in this case it has been possible to study these three units laterally, it is appreciated that it is not always possible to do so. This is a difficulty in the parts of the basin younger than the Whariki Formation, where paleoenvironments do not get much deeper than mid-shelf, and the outcrops are essentially parallel to the paleoshelf.

CHAPTER EIGHT:

A SEQUENCE STRATIGRAPHIC MODEL FOR 41 K.Y. SEQUENCES.

Introduction.

The repetitive succession of shellbeds, siltstone and sandstone units that comprise the late Pliocene-Pleistocene stratigraphic record in Wanganui Basin were first recognised as cyclothemic by Fleming (1953), who correctly stated that "The cyclothems are typically separated by disconformities representing periods when the sea-level advanced and carved wave-cut platforms after each phase of uplift and elevation and erosion of underlying beds." (Fleming, 1953 p.303). Macrofaunal analysis of the cyclic strata allowed Fleming to construct a relative sea-level curve for the Wanganui Basin Pleistocene strata, which was punctuated by numerous, brief erosion intervals coincident with sea-level rises. However, the absence of independent data for oceanic eustacy during this interval precluded further correlation with similar deposits outside Wanganui Basin. Furthermore, this was during the period in which the "4-glaciations" paradigm was in place, and he could not adopt a multi-glaciation explanation for the multiple erosion intervals.

Oxygen isotope data for which a paleomagnetic chronology was also available were first published by Shackleton & Opdyke (1973), who presented an oxygen isotope curve for the last 1.6 m.y. from core V28-238 in the Pacific Ocean. This provided an independent record of variations in ocean volume and hence of global sea-level that could be compared with the inferred sea-level changes observed in strata in onland sections. Kamp (1978) was the first to correlate shallow-water sedimentary sequences in New Zealand with an oxygen isotope curve (V28-238), and did so for the Pleistocene Cape Kidnappers section, in eastern North Island in an unpublished thesis. However, the marine Pleistocene succession in Wanganui

Basin was not correlated with an oxygen isotope curve until Beu & Edwards (1984) tentatively correlated their interpretation of molluscan depth ranges in the Castlecliff section to the oxygen isotope curve from core V28-239 (Shackleton & Opdyke, 1976; Gardner, 1982). The identification of the Brunhes / Matuyama paleomagnetic transition and Jaramillo subchron within the Castlecliff section (Turner & Kamp, 1990), allowed Kamp & Turner (1990) to correlate the cyclothems in the Castlecliff section and their bounding unconformities with the oxygen isotope curve from DSDP site 522A. This work demonstrated unequivocally that global sea-level changes were a primary control upon the accumulation of rocks in the Castlecliff section.

Confirmation that the sedimentary succession in Wanganui Basin accumulated during an interval of repetitive sea-level rise and fall meant that a sequence stratigraphic interpretation could be applied to the alternating facies within the shelfal cyclothems common in the Wanganui Basin Plio-Pleistocene succession. This was first attempted by Abbott & Carter (1994), who described the sequences within the Pleistocene Castlecliff section, and applied a sequence stratigraphic interpretation to the cyclothemic strata. This study assigned shellbeds and fossiliferous sandstone beds to the transgressive systems tract (TST), and the overlying shelf siltstone beds to the highstand systems tract (HST), with the superposition of these two main facies groups comprising a sedimentary sequence. Naish & Kamp (1995; 1997) identified 20 similar sequences in the Plio-Pleistocene Rangitikei River section, and interpreted them in a sequence stratigraphic context. This study focused on the subdivision of the TST into several constituent shellbeds, reflecting different environments of carbonate accumulation on the shelf as described by Kidwell (1991). The study by Naish & Kamp (1997) emphasised the need for definition of a new systems tract, the regressive systems tract (RST), to account for the regressive deposits that accumulated on the paleoshelf during the interval of rapid sea-level fall. Thus, the facies architecture of the Nukumaruan (late Pliocene-early Pleistocene) Rangitikei River sequences varied somewhat from those observed in the Castlecliff section (Middle Pleistocene), because the cyclothems included a third systems tract. This was not unexpected, because not only are the two sections separated by many tens of kilometres, but they are also separated in time by several hundred thousand years, and hence represent different paleoshelf positions, and accumulated during intervals of sea-level oscillations of greatly different amplitudes and periodicity (41 k.y. versus 100 k.y.). Nevertheless, Saul *et al.* (1999) presented an array of cyclothemic "motifs" from the late Pliocene and Pleistocene of Wanganui Basin, which demonstrated some of the different styles of sequence observed within strata of that age in the basin. They implied that the motif could be used as a type of sequence stratigraphic model to predict the paleoshelf position of a sequence, based on its most similar "motif" architecture. These motifs are reproduced in figure 8.1, in which seven sequences are arrayed in their expected position across a conceptual paleoshelf. All the "motifs" are considered to represent deposits that accumulated landward of the lowstand shoreline, as evidenced by marine ravinement at their lower bounding surface.

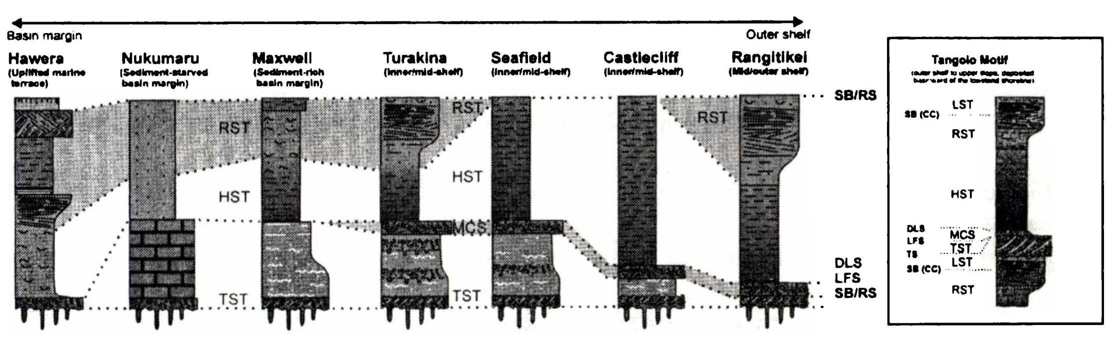


Figure 8.1: Sequence motifs based on various Plio-Pleistocene cyclothems, Wanganui Basin. (after Saul *et al.,* 1999). (The Tangoio motif is based on sequences in central Hawke's Bay).

The Seafield and Castlecliff motifs are of the type occurring in the Castlecliff section (Abbott & Carter, 1994), and the Rangitikei motif is the most common type occurring in the Rangitikei River section, as described by Naish & Kamp (1997). Other motifs are based on individual sequences from the Turakina River section (Birdgrove and Turakina), Nukumaru Beach (Nukumaru), and the Waihi Beach section (Hawera).

However, the figure is somewhat misleading, because the motifs are not coeval. Thus, time is substituted for space, and the lines drawn between motifs do not represent spatial correlations, but conceptual systems tract boundaries. Furthermore, the reference sequences on which the motifs are based are not of the same order, as some are 5^{th} order, 100 k.y. cycles (Seafield, Castlecliff), 6^{th} order, 41 k.y. cycles (Nukumaru, Birdgrove, Turakina, Rangitikei), and the Hawera motif is ~7^{th} order (Oxygen Isotope Stage 5e). An additional motif, the Tangoio, was proposed by Saul *et al.* (1999) to account for sequences with conformable bases, and containing a lowstand systems tract (LST). While based on the succession in Matapiro Syncline, cantral Hawkes Bay, and not included in the motif array for Wanganui Basin, this motif represents sequences that accumulated in a position basinward of the lowstand shoreline.

The approach of Saul *et al.* (1999) is not applicable to many of the sequences of Mangapanian and early Nukumaruan age examined in this study. An example of this is the Whauteihi Formation in the Wanganui River section, where the sequence is comprised of the Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone Members in ascending stratigraphic order. Here, no marine ravinement surface is present in the contact below the Wilkies Shellbed, and it does not contain reworked bioclastic gravels, which represent the LST in the Tangoio motif, the only conformity-bounded sequence of the "motifs" of Saul *et al.* (1999). Also, many Mangapanian sequences contain no shellbed at the lower sequence boundary, and thus cannot confidently be compared to any of the seven "motifs".

This chapter aims to present an alternative sequence stratigraphic shelf architecture model for Wanganui Basin strata based on lateral facies changes observed in the three reference sequences examined in the previous three chapters. The cross-basin analysis of the sequences that include the Mangapani Shell Conglomerate, Wilkies Shellbed and Hautawa Shellbed provide a unique opportunity to investigate lateral facies changes across a paleoshelf, and thus can incorporate elements of each sequence to create a "model" cyclothem.

Building a model cyclothem.

(n.b. – to avoid confusion, the term "sequence" is used when referring to any one of the 13 sedimentary sequences within the Paparangi and Okiwa Subgroups. The usage of the term "cyclothem" here is restricted to the conceptual model based upon these sequences.)

The three sequences investigated in Chapters 5, 6 and 7 each illustrate the two-dimensional architecture of sequences across their respective paleoshelves, and also show how mixed carbonate - siliciclastic depositional systems exhibit a generally similar character. The three sequences are illustrated in figure 8.2, in ascending stratigraphic order. While each of the sequences can also have formation names (Atene, Whauteihi and Whariki), the shellbed names are used here because while they only refer to part of each sequence, they have historical precedence and reflect a more widely used and understood useage. Figure 8.2 shows the three sequences together with the columns on which the sequences are based and the interpolated lithology between the columns. Note that while the vertical scale is the same for each sequence, the horizontal scale is different. The sequences exhibit many similarities. These include:

- Each sequence generally thins westward, and thickens eastward.
- Three main facies associations comprise each sequence, with shellbed, siltstone and sandstone facies being dominant.
- Sandstone and shellbed facies are generally thickest and dominant in the western parts, with siltstone facies being the thickest in the eastern parts, thinning and wedging out westwards, between the shellbed and sandstone facies.
- Shellbeds can occur in a variety of types; those containing reworked shallow-water fossils occur at the base of each sequence, with the preservation state decreasing westwards. In most sections, this is associated with an unconformable base to the sequence.

- The best preservation of fossils occurs in the upper parts of each shellbed, above the reworked shellbed facies, or at the base of the sequence where the lower contact is conformable.
- Sandstone units contain more sedimentary traction current structures in the west, and become more massive, finer-grained and structureless eastward.
- Molluscan depth analysis reveals that the shellbeds occurring at the base of each sequence accumulated during rising sea-level conditions, which transgressed the land surface in a westward direction.
- The molluscan paleodepths for maximum flooding generally match the thickness of the entire sequence at that locality.

The repetition of these features allows for the construction of a 2-D model cyclothem. Each of the three sequences studied provides key evidence for different parts of the paleoshelf. The Mangapani Shell Conglomerate displays the most detail of lateral shellbed architecture and geometry in the inner shelf, as well as the geometry of the terrigenous units that comprise the highstand and regressive deposits in the upper part of the sequence. Correlation to the Mangaweka Mudstone is achieved by integration of molluscan and foraminiferal biostratigraphy, but details of the sequence between the Wanganui River and Rangitikei River section are incomplete. However, the cross-shelf reconstruction of the Wilkies Shellbed sequence reveals likely details of a shelf sequence in this position, and thus allows a reasonable prediction to be made of the unexposed strata within the Mangapani Shell Conglomerate sequence. The Hautawa Shellbed sequence exhibits a similar cross-shelf sequence architecture to the Mangapani Shell Conglomerate, but also includes elements of the Wilkies Shellbed sequence, thus demonstrating the similarity between these sequences. Before proceeding with the construction of a model cyclothem based on these three sequences, a summary of their architectures and sequence stratigraphy is presented.

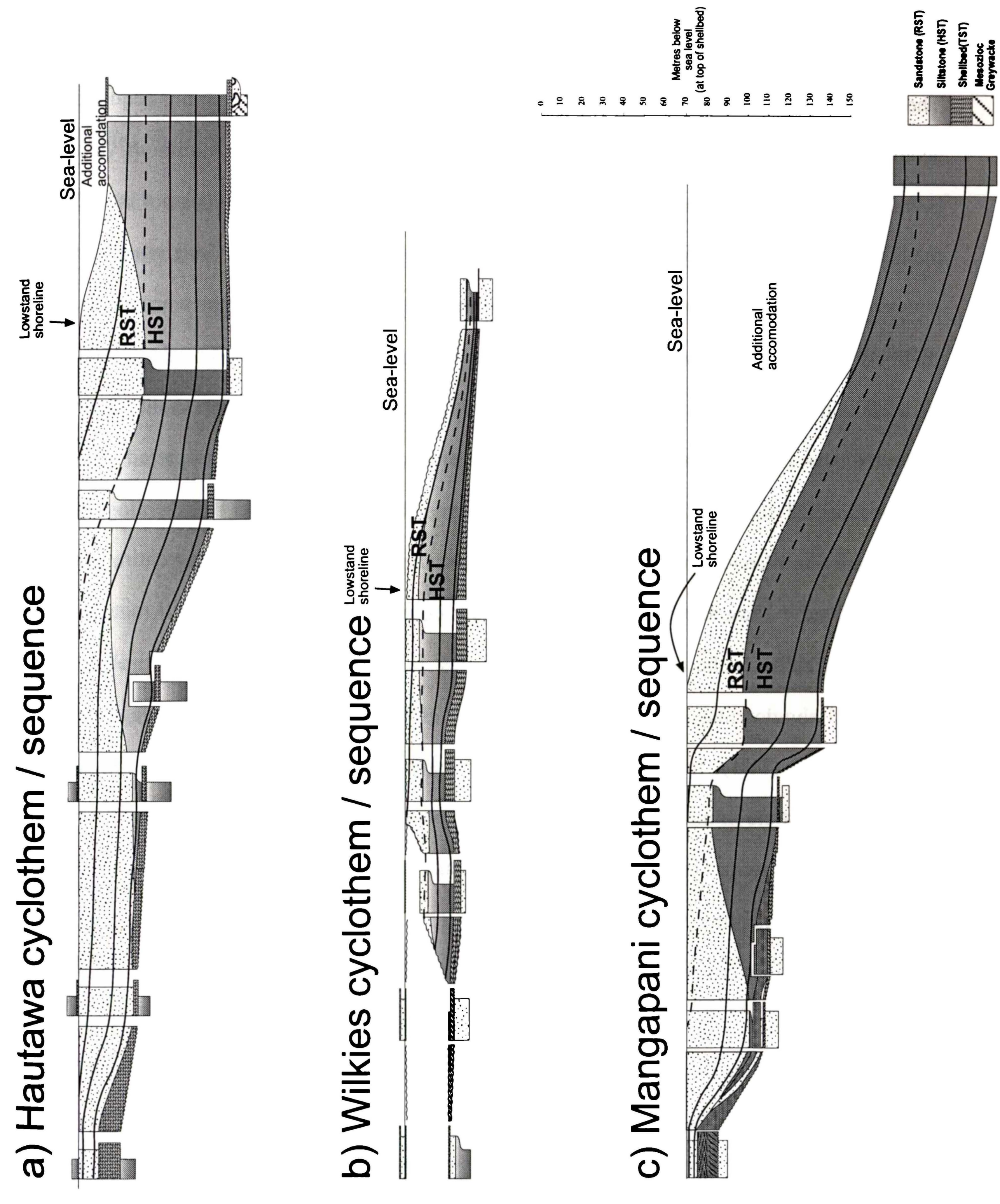


Figure 8.2: The Hautawa (a), Wilkies (b) and Mangapani (c) sequences. These three sequences form the primary basis upon which a sequence stratigraphic model has been developed. Note that the upper surface of each sequence has been flattened, palinspastically, unlike the illustrations in the chapter dedicated to each of these sequences, where the depth below highstand sea-level is based on molluscan depth range at the top of the TST.

Mangapani Shell Conglomerate:

The exposed width (immediately prior to transgression) of the shelf on which this sequence accumulated was at least 36 km, but this value must be regarded as a minimum value because the present outcrop extent of the Mangapani Shell Conglomerate does not include the highstand shoreline. Where exposed, the base of the Mangapani Shell Conglomerate is always an erosional unconformity, and the lowest part of the unit comprises an onlap shellbed. In the type section and sections to the east, this onlap shellbed is directly overlain by a backlap shellbed. In the Waitotara Road section, the onlap and backlap shellbeds are separated by ~ 1 m of decimetre-bedded siltstone and sandstone, which is interpreted as the shore-connected sediment wedge. The highly cross-bedded limestone representing the Mangapani Shell Conglomerate near Waitotara township is interpreted as being entirely an onlap shellbed. Thus, the TST is almost entirely comprised of carbonate shell material. Above the shellbed, the abrupt change in facies from shellbed to siltstone probably represents the downlap surface, reflecting a change in depositional style from retrogradational (TST), to aggradational and progradational stacking patterns (HST and RST). The siltstone immediately above the Mangapani Shell Conglomerate is regarded as the Highstand Systems Tract (HST). It represents a sudden cessation of stratigraphic condensation, coinciding with a change in the rate of relative sea-level rise. Sparsely fossiliferous mollusc concentrations in the base of this siltstone probably represent downlap shellbeds, formed by weak stratigraphic condensation at the distal toes of prograding clinoforms. While siltstone occurs immediately above backlap shellbeds, in sections where only an onlap shellbed represents the TST, sandstone rests directly upon it. Thus, both siltstone and sandstone units represent HST deposits, and in this case, there appears to be a relationship between the TST shellbed architecture and the type of HST deposit above it. Identification of the regressive systems tract (RST) part of the sequence is somewhat problematic, but the sandstone in the upper part of the sequence in the Wanganui River valley section (Atene Sandstone) is probably an RST deposit, as the thickness of the sequence at this site suggests that there was sufficient accommodation for accumulation to occur as sea-level approached lowstand.

Wilkies Shellbed:

The Wilkies Shellbed is exposed for a strike length of 51 km and displays less cross-shelf variability then the Mangapani Shell Conglomerate. The present outcrop belt is probably more shore-parallel than for the Mangapani Shell Conglomerate. Because the erosion surface beneath the Mangamahu Shellbed progressively truncates successively older sequences to the west, the Wilkies Shellbed has the best potential in the basin to form the basis for a sequence stratigraphic model. It also extends across the point seaward of the lowstand shoreline where wavebase erosion occurred, the so called Point "X". Seaward of Point "X", the TST is comprised of a backlap shellbed only, with *in situ* oysters (*Crassostrea*) resting upon the conformable sequence boundary. West of Point "X", that is landward, an onlap shellbed overlies the sequence boundary, and is overlain by a backlap shellbed. Above the backlap shellbed, the HST comprises siltstone. A sandy HST has not been observed in outcrop for the Wilkies Shellbed sequences.

Hautawa Shellbed:

The outcrop belt of the sequence in which the Hautawa Shellbed occurs is almost certainly less shore-normal than the Mangapani Shell Conglomerate and Wilkies Shellbed sequences. It crops out near-continuously for 103 km across Wanganui Basin. Thus, variations in the sequence architecture are more gradual with distance in a east-west direction. However, subtleties in both shellbed and sequence architecture reveal patterns consistent with the other sequences observed in this study. In the Rangitikei River section the base of the Hautawa Shellbed rests conformably upon the underlying sequence, and occurs here as a backlap shellbed only. West of this locality, the lower sequence boundary becomes unconformable, and is accompanied by an onlap shellbed, which overlies the transgressive surface of erosion (TSE). The onlap plus backlap (compound) shellbed nature of the Hautawa Shellbed in the central parts of the basin west of the Rangitikei River section continues into the Kauarapaoa valley section. Further to the west, the Hautawa Shellbed grades laterally into the Kuranui Limestone, which is interpreted as an onlap shellbed, with no backlap shellbed component. Details of the stratigraphy within the transition from compound shellbed (Hautawa) to onlap shellbed (limestone) only (Kuranui) are unknown, as they are concealed in heavy forest cover. Above the shellbed, scattered *in situ* shells within the lower part of the siltstone overlying the shellbed are interpreted as a downlap shellbed. The siliciclastic units above the Hautawa Shellbed / Kuranui Limestone closely mimic the comparable part of the stratigraphy in the Mangapani Shell Conglomerate sequence, with highly cross-bedded sandstone (HST) directly overlying the carbonate-rich TST in the westernmost sections. This pattern occurs in and to the west of the Wanganui River section, with a siltstone bed intervening between the shellbed and sandstone in and to the east of the Parihauhau Road section. This is somewhat different from the Mangapani Shell Conglomerate sequence, where HST as sandstone occurs only above the onlap shellbed. In the Hautawa Shellbed sequence, HST sandstone occurs both above the onlap-only part of the TST, and also above the TST when it is represented by a compound shellbed. The HST grades upwards into an RST, but the systems tract boundaries cannot be precisely located, except in broadly distal locations which accumulated in the late stage of relative sea-level fall, and thus can either be siltstone or sandstone.

The above examples illustrate the close linkage between systems tracts and shellbed types across the shelf. Facies characteristics and the identification of sequence stratigraphic surfaces are the basis for the model sequence developed here. Some of the features are as follows:

- The lower sequence boundary includes both the TSE and the CC (Correlative Conformity).
- Onlap and compound shellbeds overlie TSEs, and Backlap Shellbeds overlie CCs.
- Onlap shellbeds generally thicken shoreward, and can represent the entire TST in the nearshore position.
- Backlap shellbeds are separated from the onlap shellbed by terrigenous material (shore-connected sediment wedge or SCW) in nearshore environments, and unlike the onlap shellbed, are not connected to the paleoshoreline.
- HST sandstone can overlie the TST in the shallowest part of the sequence. A sandy HST can also extend basinward as far as to overlie a small part of the backlap shellbed.
- Where the TST is represented by only a backlap shellbed, it is overlain by siltstone.
- The RST sandstone at the top of a sequence can extend seawards to the seaward limit of the backlap shellbed.

One of the most obvious similarities in the geometry of these three sequences is reflected in their vertical asymmetry, with the retrogradational carbonate-rich TST being significantly thinner than the overlying aggradational and progradational terrigenous HST and RST deposits (Naish & Kamp, 1997). The overall geometry of each sequence is similar to a clinoform, thinning both landward and basinward, with the thickest part of the sequence being in the vicinity of Point "X". This position on the shelf has a moderate rate of sediment supply, and maintains sufficient depth throughout the accumulation of the sequence to have sufficient accommodation for the accumulation of sediment delivered to the shelf. This feature is evident in both the Wilkies and Hautawa Shellbed sequences, and is therefore included in the model cyclothem (Figure 8.3). The model cyclothem is displayed in two ways, one showing the depositional architecture (thickness / distance) and the other as a chronostratigraphic panel accompanied by a relative sea-level curve. Key surfaces and systems tracts are also shown in figure 8.3. The profile of the model as depicted here represents a shore-normal vertical section through the cyclothem immediately following its accumulation, minimal subaerial erosion having taken place. If the figure were to include both the effects of substantial subaerial and transgressive erosion following accumulation of the cyclothem, then truncation of both strata and clinoforms at the top of the cyclothem would result. This is considered to have occurred in the Wilkies Shellbed sequence in the western parts of the basin, which has undergone significant truncation.

One important assumption used in the formulation of the model cyclothem is that the amplitude of the eustatic sea-level rise and fall are equal. When the sea-level change is added to the tectonic subsidence component, relative sea-level rises will be greater in amplitude than the subsequent relative sea-level fall. Thus, as successive cyclothems accumulate on the shelf, the lowstand shoreline positions should move basinward in a progradational fashion. If the succeeding lowstand shoreline were to be plotted on figure 8.3, it would be predicted to occur on the upper surface of the model cyclothem somewhere above and to the right of the location of "Point X". This pattern is typical of "advancing" clinoforms (Galloway in Muto & Steel, 1997).

One feature observed in both the Mangapani and Hautawa Shellbed sequences in outcrop is an interval of abnormal thickening in the upper sandstone part of the sequence in its more basinward parts. While this feature *could* be due to a tectonic overprint, its occurrence in both of these sequences indicates that it is probably due to normal seaward reworking of terrigenous material during the regressive phase of a relative sea-level fall. This feature of the sandstone geometry represents the Regressive Systems Tract (RST), which prograded basinward in a forced manner as accommodation on the emerging inner shelf was being progressively reduced. The progradation ceased when relative sea-level started to rise. There will be a surface separating the HST and RST, but it may not coincide with any lithological boundary, and indeed will cut across facies boundaries (Figure 8.3).

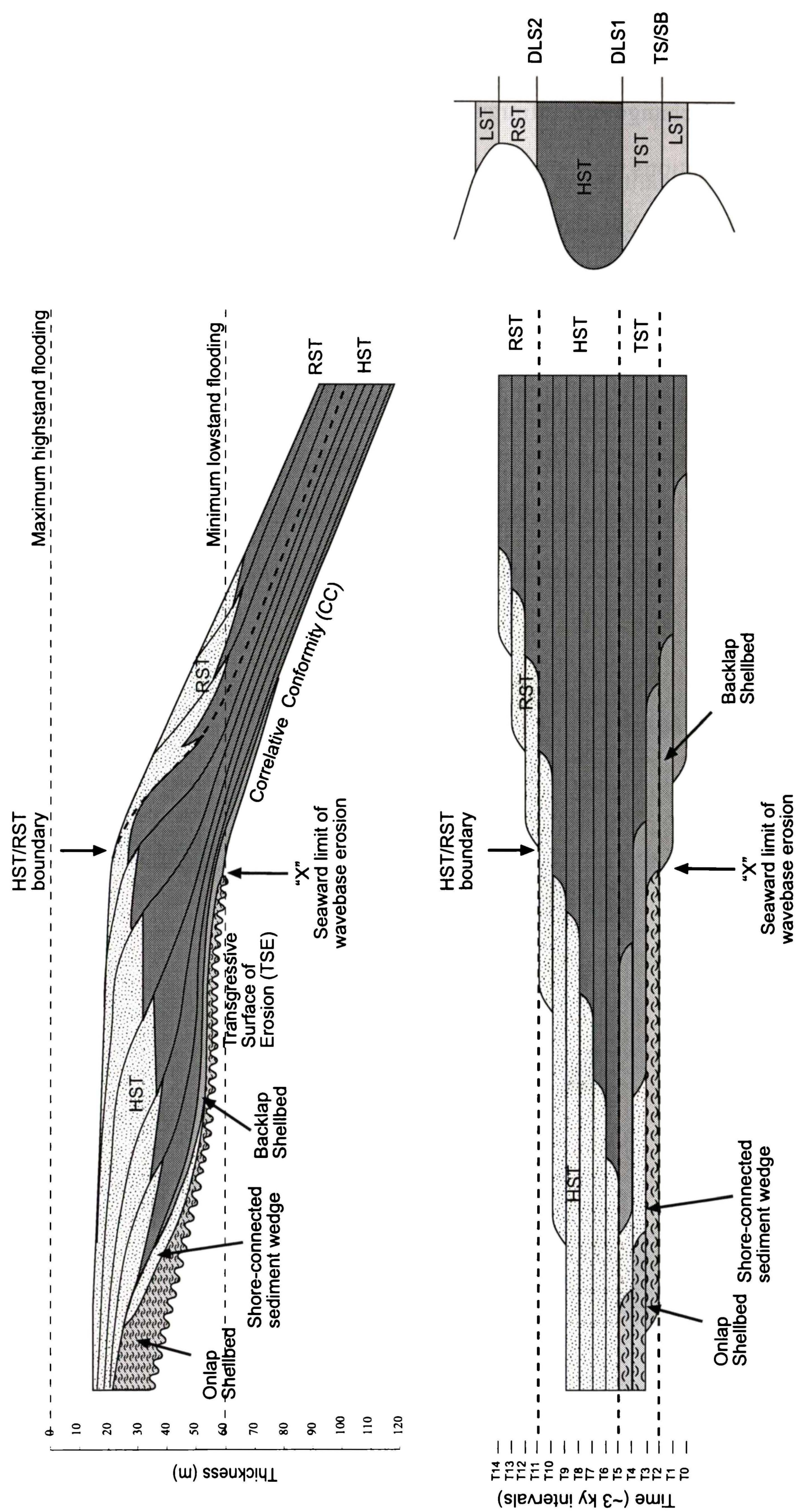


Figure 8.3: Generic model cyclothem for Mangapanian shelf sequences, Wanganui Basin, with expected facies in their relative basinward position. Scale approximate; horizontal distance about 20 km, VE ~ 200x.

Naturally it is realised that the model cyclothem is not always 100% representative of a given sequence as seen in outcrop. The rate of tectonic subsidence, the sediment supply and eustatic sea-level change are infinitely variable, and will result in different depositional scenarios and variations in sequence architecture. Examples are differences in the extent of highstand sandstone progradation over the Mangapani Shell Conglomerate and Hautawa Shellbed. Another example is the presence or absence of sandstone in the upper parts of a sequence in the vicinity of the HST / RST division clinoform. In some sequences, it appears that sandstone of the HST is not connected with sandstone of the RST, and these two units, while of the same lithology, have no depositional linkage and are separated by siltstone. Since variations in the shape of the RST is due to variation in the rate of sediment supply, it cannot be fully accommodated in the model cyclothem.

Comparison of other Mangapanian sequences in the succession with the model cyclothem.

In the thesis up to this point the Mangapanian sequences other than the three studied in detail have not been subjected to the same level of sequence stratigraphic interpretation. To what extent do they exhibit lateral change in geometry, facies architecture and thickness consistent with those predicted by the model cyclothem? A test of this type may highlight the variability in sequence architecture, the details of which cannot be included in a model, but should able to be accomodated / explained by it.

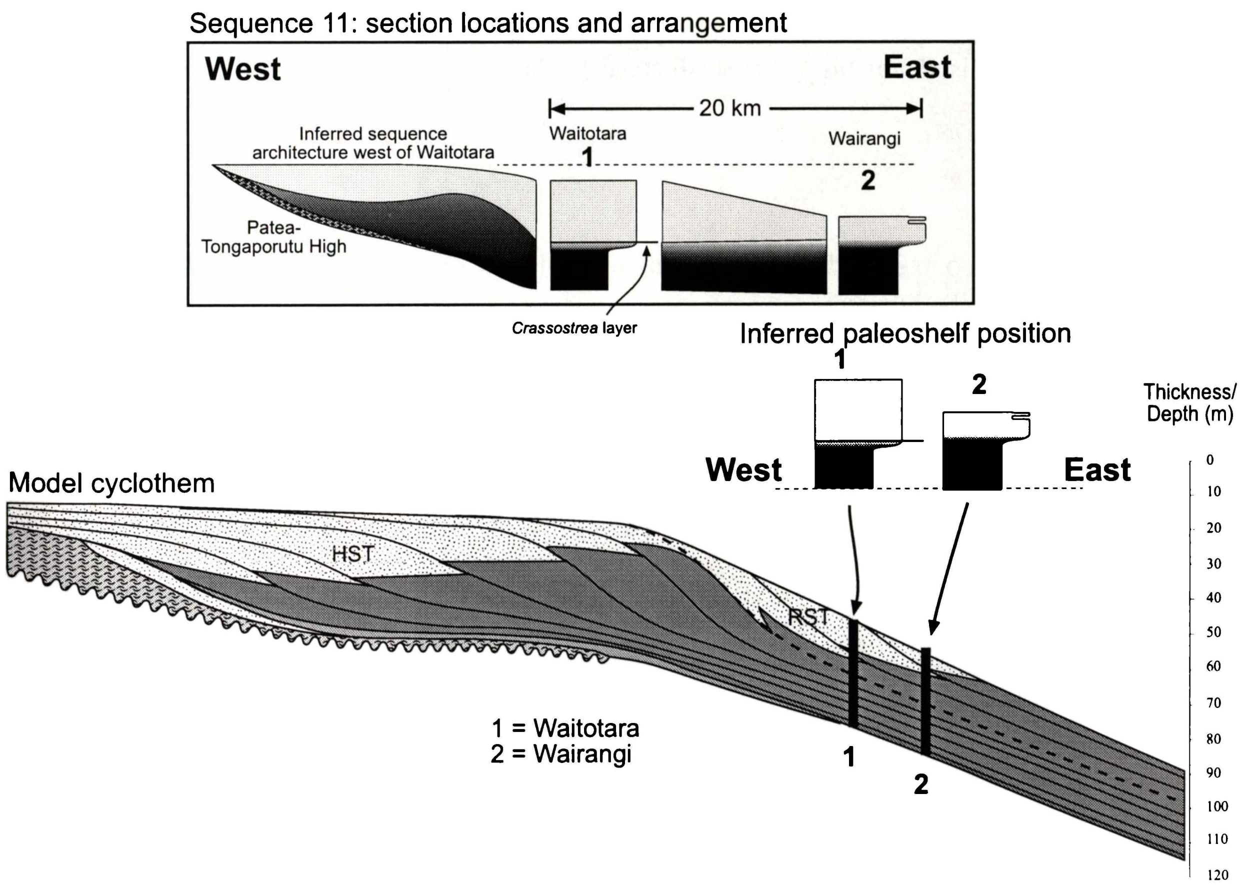


Figure 8.4: Sequence 11, lower Pitangi Formation positioned conceptually on model cyclothem.

Sequence 11: Lower Pitangi Formation: (Figure 8.4)

Columns of two sequences that comprise the lower part of the Pitangi Formation in the Waitotara River and Wairangi sections are placed against the model cyclothem in figure 8.4. These are the only two localities in which this sequence is exposed in Wanganui Basin. At both sites where this sequence can be observed the base is conformable, meaning that sedimentation began in a shelf position basinward of Point "X". Neither section contains a shellbed at its base, and the sequence probably accumulated basinward of the deepest extent of the backlap shellbed. Further evidence for a relatively deep origin of these sections is the transition into the Mangaweka Mudstone in the Wanganui River valley. The Mangaweka Mudstone is a featureless, outer-shelf siltstone (see Chapter 4). The thin layer of *in situ* *Crassostrea* specimens in the lower part of the sandstone in the Waitotara section probably represents a localised downlap surface formed at the toe of a prograding clinoform (see Figure 8.5).

Abbott (2000) also reported *Ostrea* downlap shellbeds in parts of the mid-Pleistocene Castlecliff section, and the inferred similarity between the preferred habitat of *Ostrea* and *Crassostrea* means that a similar sequence stratigraphic interpretation for this type of shellbed can be used. This shellbed is a clinoform boundary and may mark the HST / RST boundary. The eastward thinning of the sequences is not well accounted for by the model, and may be due to a steeper slope on of the upper surface of the sequence than shown on the model.

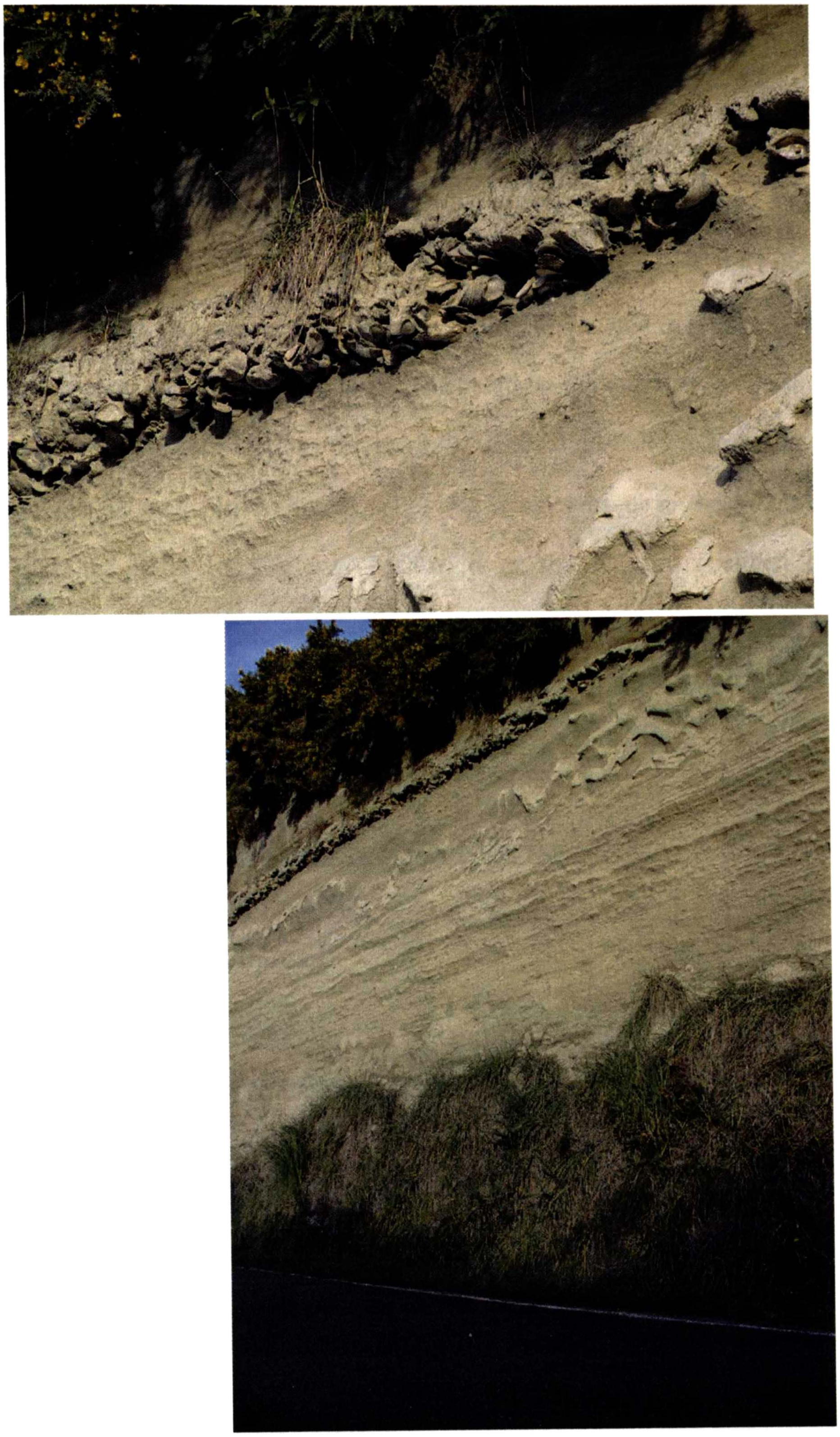


Figure 8.5: *Crassostrea* downlap shellbed within Sequence 11, Lower Pitangi Formation. Shellbed is 0.3 m thick, and ~ 10 m above road level.

Sequence 10: Middle Pitangi Formation: (Figure 8.6)

Sequence 10 represents the middle part of the Pitangi Formation, and conformably overlies sequence 11. It crops out in the Waitotara River and Wairangi sections. The sequence grades into the Mangaweka Mudstone in the vicinity of the Wanganui River valley. As with the previous example, the two sections probably both accumulated in relatively deep water, in a position basinward of Point "X", as demonstrated by the correlative conformity at the base of the sequence in both sections (Figure 8.6). A backlap shellbed occurs at the base of the westernmost sequence in Waitotara valley but is not present in the Wairangi section, meaning that the latter locality was basinward of the backlap shellbed during the accumulation of the TST. The sall thickness of siltstone could be explained by a rapid regression following the relative sea-level highstand, coupled with a high rate of sediment supply during the regressive phase of sea-level history.

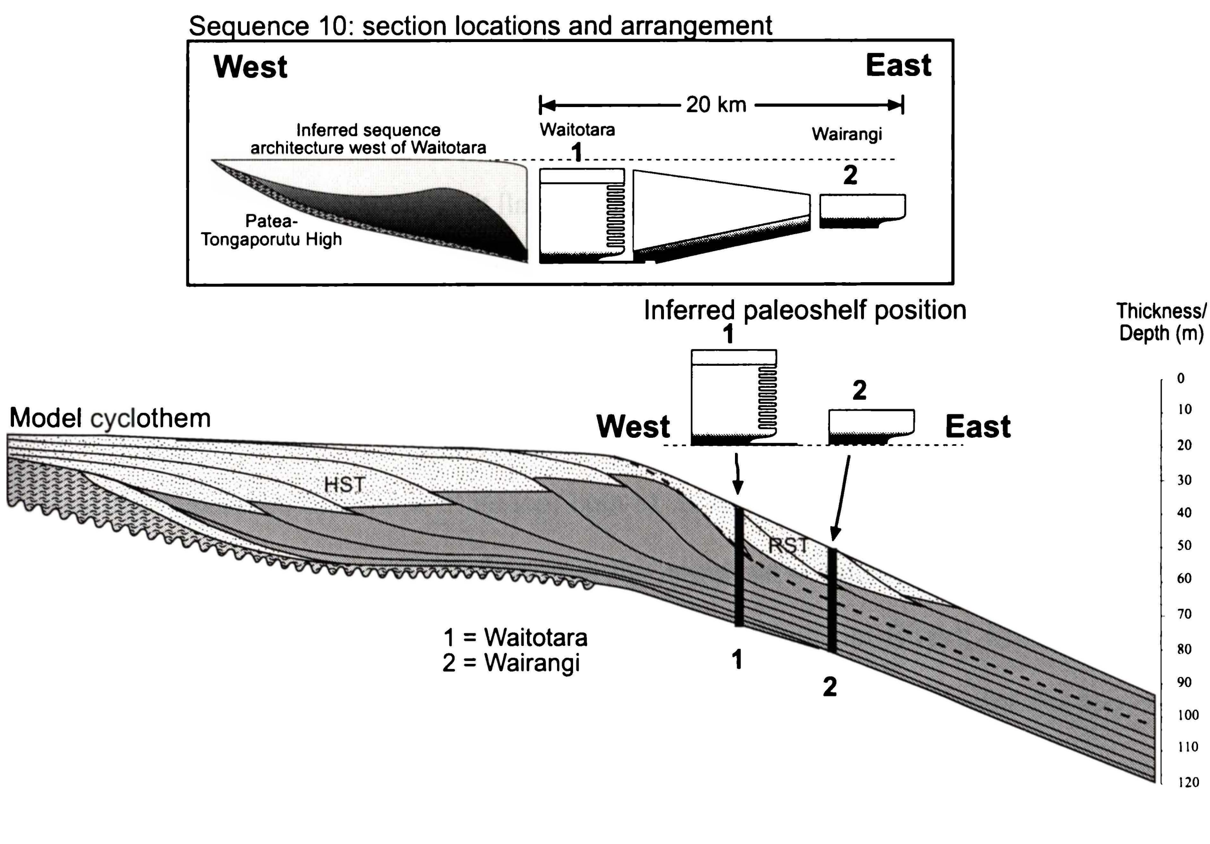


Figure 8.6: Sequence 10, middle Pitangi Formation positioned conceptually on model cyclothem.

Sequence 9: Upper Pitangi Formation, Gully Shellbed: (Figure 8.7)

As illustrated in figure 8.7, the uppermost part of the Pitangi Formation crops out in four laterally adjacent sections, extending from Okiwa Trig (1) to Wairangi (2) and the Wanganui (3) and Whangaehu (4) River valleys. Eastward of the last locality it grades into the Mangaweka Mudstone. At Okiwa, the Gully Shellbed marks the base of the sequence, which is unconformable with silty sandstone sharply overlying loose sandstone. While no onlap shellbed is preserved, leached casts of indeterminate bivalves within sandstone indicate post-depositional carbonate dissolution. However, the backlap shellbed is well preserved, and the intervening 6.5 m of terrigenous material grades upward from sandstone to siltstone, and is thus interpreted as the shore-connected sediment wedge (SCW). This onlap-SCW-backlap motif is characteristic of a shoreline-proximal, late stage TST, and thus corresponds to the relatively shoreward part of the model cyclothem. Furthermore, the siltstone and sandstone above the shellbed are consistent with that predicted by the model cyclothem as accompanying such a TST architecture, indicating that at this locality both the siltstone and sandstone belong to the HST. While no shellbed occurs at the base of either the Wairangi, Wanganui and Whangaehu sequences, they can be quite confidently positioned in the deeper-water parts of the model, as all their bases are conformable, and (3) and (4) occur somewhere within the Mangaweka Mudstone. Thus, the total thickness of the siltstone part of both (3) and (4) is uncertain. However, the upper sandstone part of both sequences is almost certainly an RST deposit, as only siltstone occurs beneath the sandstone.

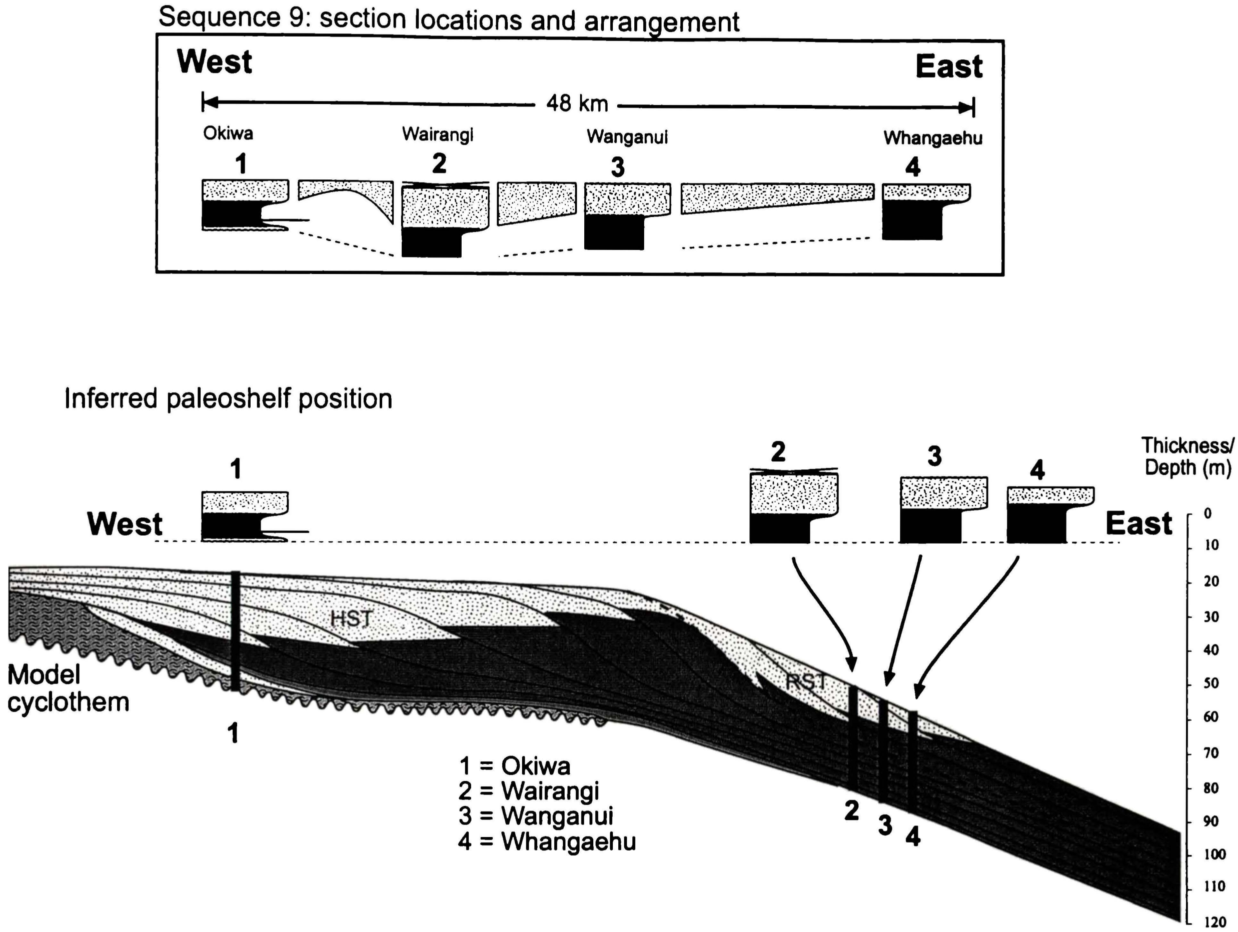


Figure 8.7: Sequence 9, upper Pitangi Formation positioned conceptually on model cyclothem. Gully Shellbed marks base of sequence at Okiwa.

Sequence 8: Moukuku Formation, Otere Shellbed: (Figure 8.8)

The exposed parts of the Moukuku Formation sequence are plotted in their likely positions on the model cyclothem on figure 8.8. This sequence includes the Otere Shellbed at its base and the Makokako Sandstone at its top; both of these show lateral variation from west to east across the basin. A striking feature of this sequence is the location of the shallowest part of the sequence in the central parts of the basin (Wanganui River), with progressive deepening inferred for sites to the east and west. The most basinward site for this sequence is considered to be at Okiwa (1), where the base of the sequence is marked by a conformable, upward fining from sandstone to siltstone. The three thin shellbeds with the siltstone are probably downlap shellbeds lying on clinoforms, as the fauna is *in situ* and their monospecific occurrence is uncharacteristic of a backlap shellbed. Siltstone dominates the sequence here, which together with the relatively thin RST is consistent with a more basinward position compared with the other outcrop examples of this sequence. Neither the base of the sequence nor the Otere shellbed are exposed in either the Paparangi (2) or Wairangi (3) sections, which are considered to have accumulated in relatively shallower environments than at Okiwa, due to a subtle progressive thinning in an eastward direction. At Paparangi, a thin downlap shellbed near the top of the siltstone could possibly be a correlative of one of the downlap shellbeds in the sequence at Okiwa; its closer proximity to the RST Makokako Sandstone indicates that the sequence accumulated in a slightly more shoreward environment at Paparangi compared with Okiwa. The Otere Shellbed is best developed in the Kauarapaoa (4) and Wanganui (5) valleys, where its base is unconformable and overlain by a compound shellbed. The sequence at the Wanganui locality is considered to have accumulated in a slightly more shoreward paleoshelf position than its counterpart in the Kauarapaoa valley, as the Makokako Sandstone is thicker there. The model predicts that the sandstone here is part of the HST, and this interpretation is supported by the occurrence of thin horizons of reworked, diverse molluscs of shallow-water origin (e.g. *Divaricella, Dosinia*), which are consistent with toplap shellbeds in the sense of Kidwell (1991). The sequence is not fully exposed in the Parihauhau Road section (6), and so is presumed to represent an intermediary position on the paleoshelf between the Wanganui (5) and Whangaehu (7) valley sections, where at the last locality its greater thickness implies that it accumulated in a deeper water-shelf position compared with its Wanganui correlative. However, the unconformable base of the shellbed means that deposition here occurred landward of Point "X". The highly leached nature of the strata precludes further subdivision of the shellbed, but a backlap shellbed is inferred to have once been present from the significant thickness of siltstone within the sequence. To the east of the Whangaehu valley, the sequence passes into the deeper water Mangaweka Mudstone.

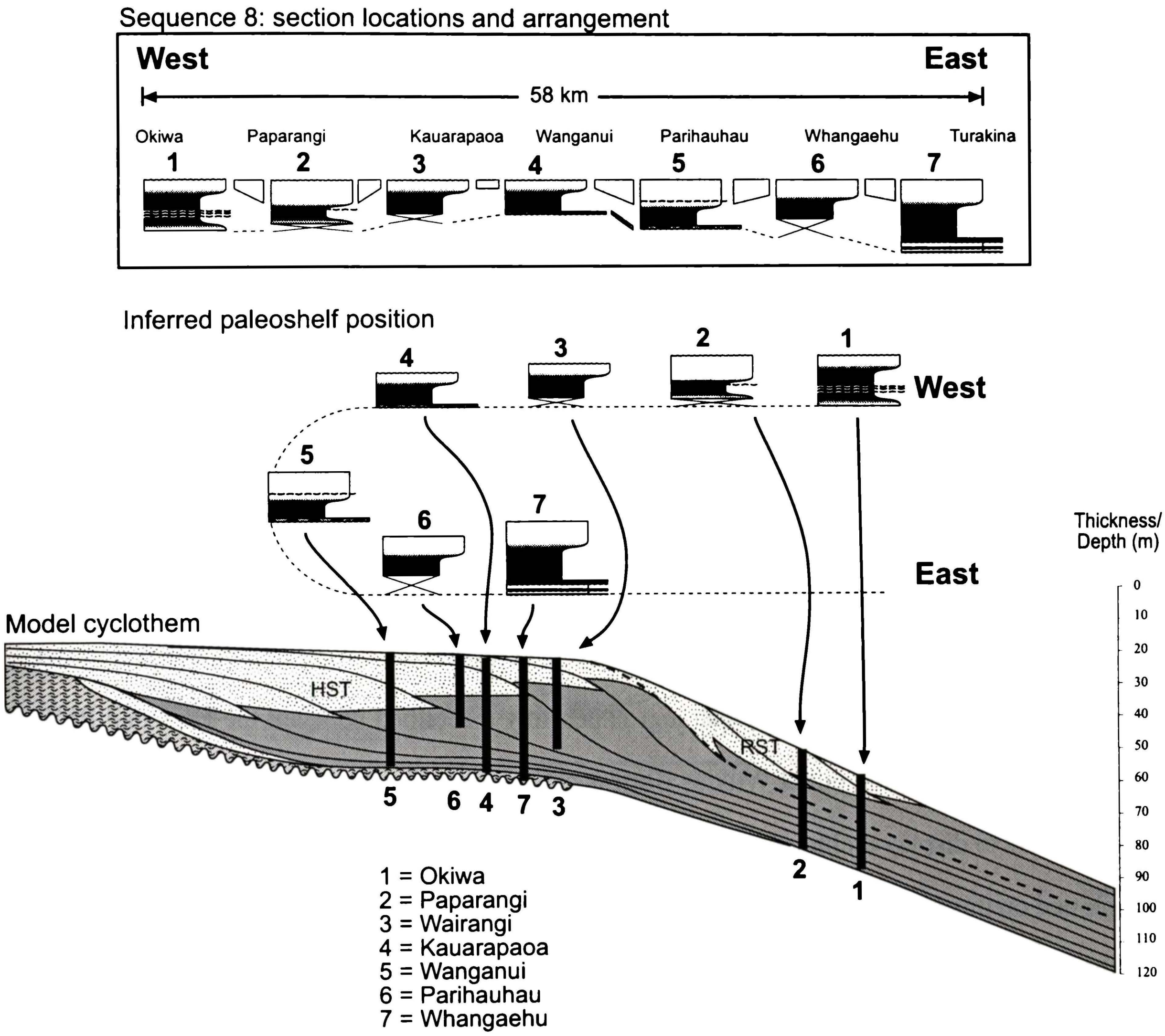


Figure 8.8: Sequence 8, Moukuku Formation positioned conceptually on model cyclothem. Otere Shellbed marks base of sequence.

Sequence 6: Lower Whakaihuwaka Formation, Mangamahu Shellbed: (Figure 8.9)

This sequence appears to represent a generally westward shallowing paleoshelf, as shown by the nature of the Mangamahu Shellbed at the base of this sequence in the western part of the basin. At Paparangi (2), the shellbed has a well-defined onlap part, and the thick sandstone bed above the onlap shellbed is consistent with a shore-connected sediment wedge (SCW). One notable aspect of the shellbed at this locality is the very poorly developed nature of the backlap shellbed at the top of the SCW, indicating that this site probably represents the shoreward limit of the backlap shellbed. The sequence at Okiwa (1) is similar to the one at Paparangi, but a fault obscures critical details of the lower part of the sequence. However, an onlap shellbed is present, and the general consistency of thickness and lithology of the sequence in these two sections infers that they accumulated in much the same manner. One anomalous feature of the sequence in these two sections is the disparity between the shallow-water shellbed and the lack of overlying HST sandstone. This is probably due to an increase in the rate of tectonic subsidence, which provided additional accommodation. This effect is illustrated in figure 8.9, where the transect through the model cyclothem curves basinward to show the basinward shift in facies upwards through the sequence. The absence of sandstone at the top of the sequence cannot be attributed to erosion, as the upper contact of the sequence is conformable. A thin shell horizon in the upper part of the sequence at Paparangi is possibly a shellbed between the HST and RST. The shellbed cropping out at Wilkies Bluff is considered to be the Mangamahu Shellbed, as it appears to display architecture similar to the Mangamahu Shellbed at Paparangi, but is not plotted on this figure because difficulty of access to this site precludes close investigation of the internal features and bedding surfaces associated with the shellbed. The sequence is well exposed in the Kauarapaoa valley (3), where the Mangamahu Shellbed maintains an onlap-SCW- backlap character, but the thinner SCW and thicker backlap shellbed compared with the Paparangi (2) correlative indicates that it accumulated in a relatively deeper water setting. The presence of sandstone (HST) at the top of the sequence in this section suggests that the deepening inferred for the aforementioned Paparangi (2) and Okiwa (1) sections did not occur here. Thus, an abrupt deepening is inferred to have occurred between the Paparangi (2) and Kauarapaoa (3) sequences during the late stages of their accumulation, the western part subsiding relative to the eastern part of the basin at this time to form a westward-plunging monocline. The sequence gradually thickens eastwards from the Kauarapaoa valley into the Wanganui (4), Parihauhau (5) and Whangaehu valley (6) sections. In the Whangaehu valley the Mangamahu Shellbed is a compound shellbed, unconformably overlying the Te Rimu Sandstone. The lack of sandstone in the upper part of the sequence here is possibly due to proximity to the HST / RST transition at this locality, as shown on figure 8.9. The Mangamahu Shellbed is not present at Parihauhau, but the relatively thick sandstone at the base of the sequence is interpreted as a SCW. The character of the sequence in the Turakina valley (7) is markedly different to its western correlatives, but its barren, conformable base indicates a relatively deep-water depositional environment, basinward of both Point "X" and the backlap shellbed. To the east of the Turakina valley, the sequence passes into Mangaweka Mudstone.

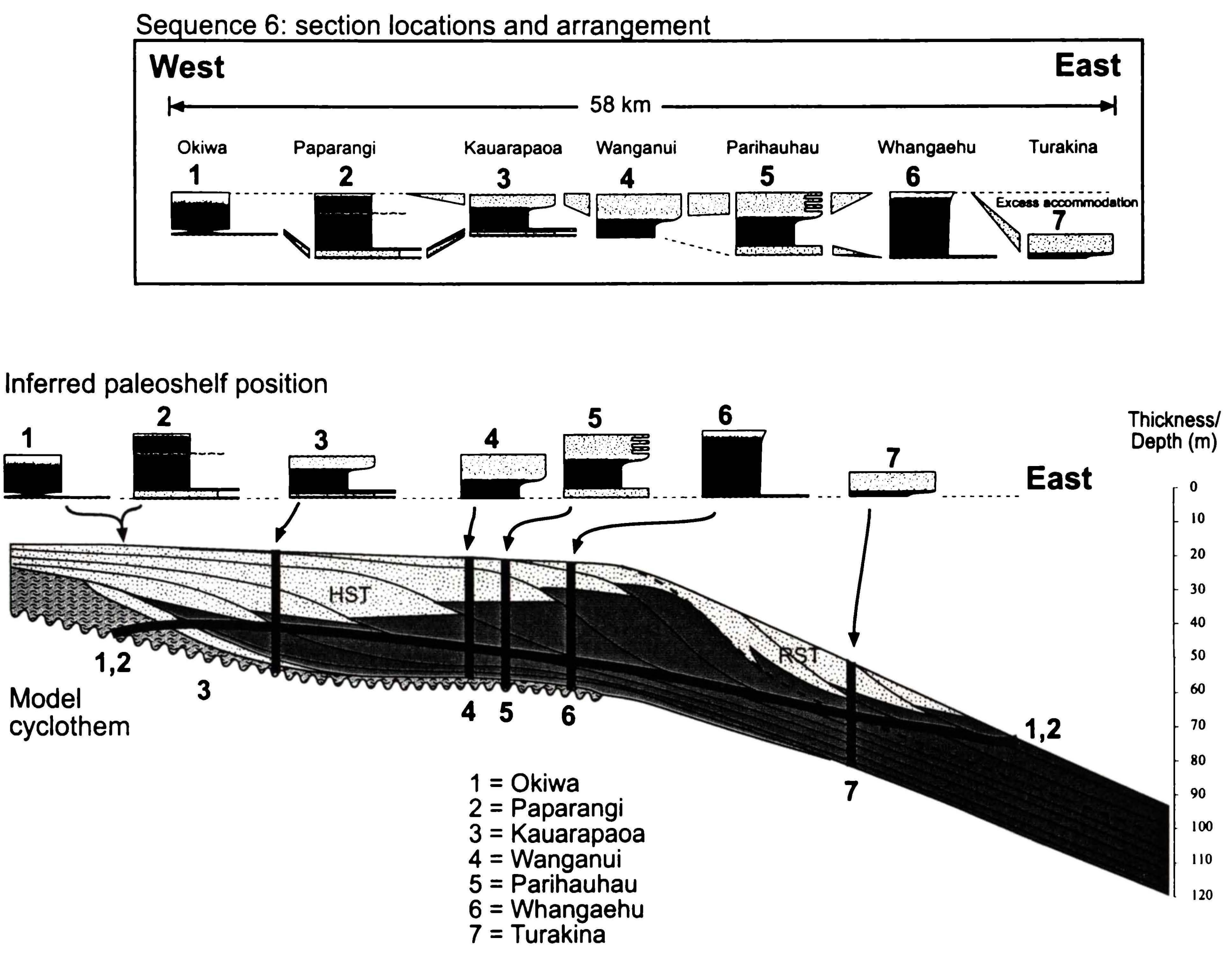


Figure 8.9: Sequence 6, lower Whakaihuwaka Formation positioned conceptually on model cyclothem. Mangamahu Shellbed marks base of sequence.

Sequence 5: Upper Whakaihuwaka Formation, Tirotiro Shellbed: (Figure 8.10)

In the western parts of the basin, at Okiwa (1) and Paparangi (2) this sequence retains a similar architectural motif to preceding sequence 6 with no sandstone present in the upper part of the sequence. However, the Tirotiro Shellbed at the base of the sequence is markedly different, with only a backlap shellbed present, conformably overlying siltstone in both these sections. Both these observations indicate a relatively significant depth of water (~ 50–60 m) in this region prior to the accumulation of this sequence in a position basinward of Point "X", almost certainly the result of the accelerated tectonic deepening that occurred in sequence 6. The sequence is thicker in the Kauarapaoa valley (3), but the occurrence of a double sequence in this part of the succession indicates parasequences development. The part of the upper sequence appears to be similar in thickness to correlatives at Okiwa (1) and Paparangi (2), while the lower part has a similar thickness and stratigraphic architecture to the correlatives in the Wanganui (4) and Parihauhau (5) sections. The shellbeds in the lower part of the sequence form a compound shellbed, which places the base of the sequence in a position slightly landward of Point "X", an inference supported by the presence of relatively thin sandstone (HST) rather than siltstone in the uppermost part of the sequence. The sequence is dramatically thinner in the Wanganui River valley (4), and the compound shellbed at its base is well developed. Textural data shows that the siltstone above the shellbed contains a high amount of sand, which, when combined with the thickness of the sequence, suggests that this locality represents the overall shallowest depositional environment of the sequence. East of Wanganui River, the sequence thickens into the Parihauhau Road section (5), but lack of exposure of the Tirotiro Shellbed at the base of the sequence precludes accurate positioning of the sequence on the model cyclothem. However, the increase in thickness indicates that the sequence accumulated in a slightly deeper environment than its correlative in the Wanganui River section. The Tirotiro Shellbed is well exposed in the Whangaehu River section (7), conformably overlying sequence 6 as a thin backlap shellbed. The thin, poorly developed nature of the shellbed constrains its position to a point basinward of Point "X", within the backlap shellbed can occur. This position on the model cyclothem is consistent with both the thick siltstone and thin HST sandstone observed above the shellbed in outcrop, both of which indicate a proximity to the HST / RST transition. In the Turakina River valley (7), the base of the sequence is not exposed in the roadside section, but the thickening of the sandstone at the top of the sequence compared with its correlative in the Whangaehu section (6) is interpreted as the sandstone being part of the RST, as illustrated in figure 8.10. To the east of Turakina valley, the sequence cannot be traced with confidence, but almost certainly lies within the Mangaweka Mudstone in the Rangitikei River section, which is a considerably deeper-water facies compared with the aforementioned localities.

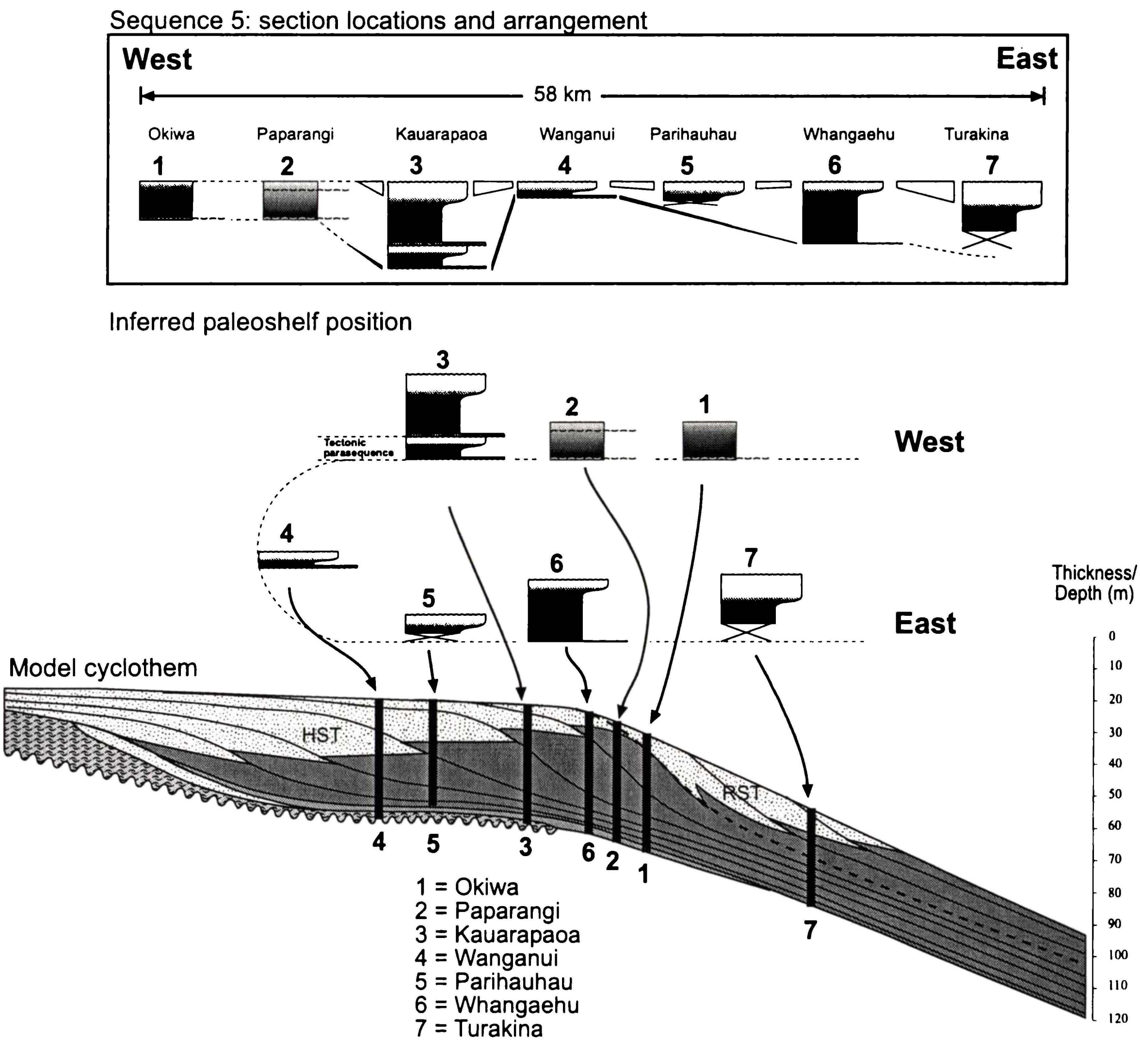


Figure 8.10: Sequence 5, upper Whakaihuwaka Formation positioned conceptually on model cyclothem. Tirotiro Shellbed marks base of sequence.

Sequence 4: Lower Parikino Formation, Te Rama Shellbed: (Figure 8.11)

Figure 8.11 illustrates the interpreted paleoshelf positions of various parts of sequence 4 on the model cyclothem. The Te Rama Shellbed is present in seven of the eight localities illustrated in this figure, the exception being the Wairangi section, where its absence is very likely due to complete dissolution of the shellbed as a result of extensive meteoric leaching. In the type section at Okiwa (1), the base of the Te Rama Shellbed is conformable, which is consistent with the Te Rama being a backlap shellbed. However, the presence of disarticulated and broken shell material in the lower parts of the shellbed here indicates proximity to an onlap environment, with possible reworking of carbonate debris from an onlap environment down "slope" to this locality. The shellbed is thinner and better preserved at Paparangi (2) than at Okiwa, but has a conformable base and much the same level of faunal preservation, suggesting a similar depositional environment for both localities. A thin *Atrina* horizon ~ 1 m above the backlap shellbed here is probably a downlap shellbed. While the Te Rama Shellbed is not present at Wairangi (3), the general accordance of thickness of the sequence in these three sections and their conformable lower bounding surface indicates that they accumulated in much the same position on the paleoshelf, in a position slightly basinward of Point "X". In the Kauarapaoa valley (4) section, the sequence is markedly thinner than further west and east, and the Te Rama Shellbed is a compound shellbed, unconformably overlying sequence 5. Thus, a significant eastward shallowing is inferred between the from the Wairangi (3) to the Kauarapaoa (4) sections. A remarkable similarity exists for the sequence in the Kauarapaoa (4), Parihauhau (6) and Whangaehu (7) sections, and thus all three localities are plotted in the same position on the model cyclothem. Textural analysis reveals that of the three, the sequence at Parihauhau contains the greatest proportion of sand, and the siltstone part contains a sand content of almost 50%. Thus, for these examples, the Parihauhau (6) section probably represents the sequence in its most shoreward position. In the Wanganui River (5) section, the sequence reaches its greatest thickness.

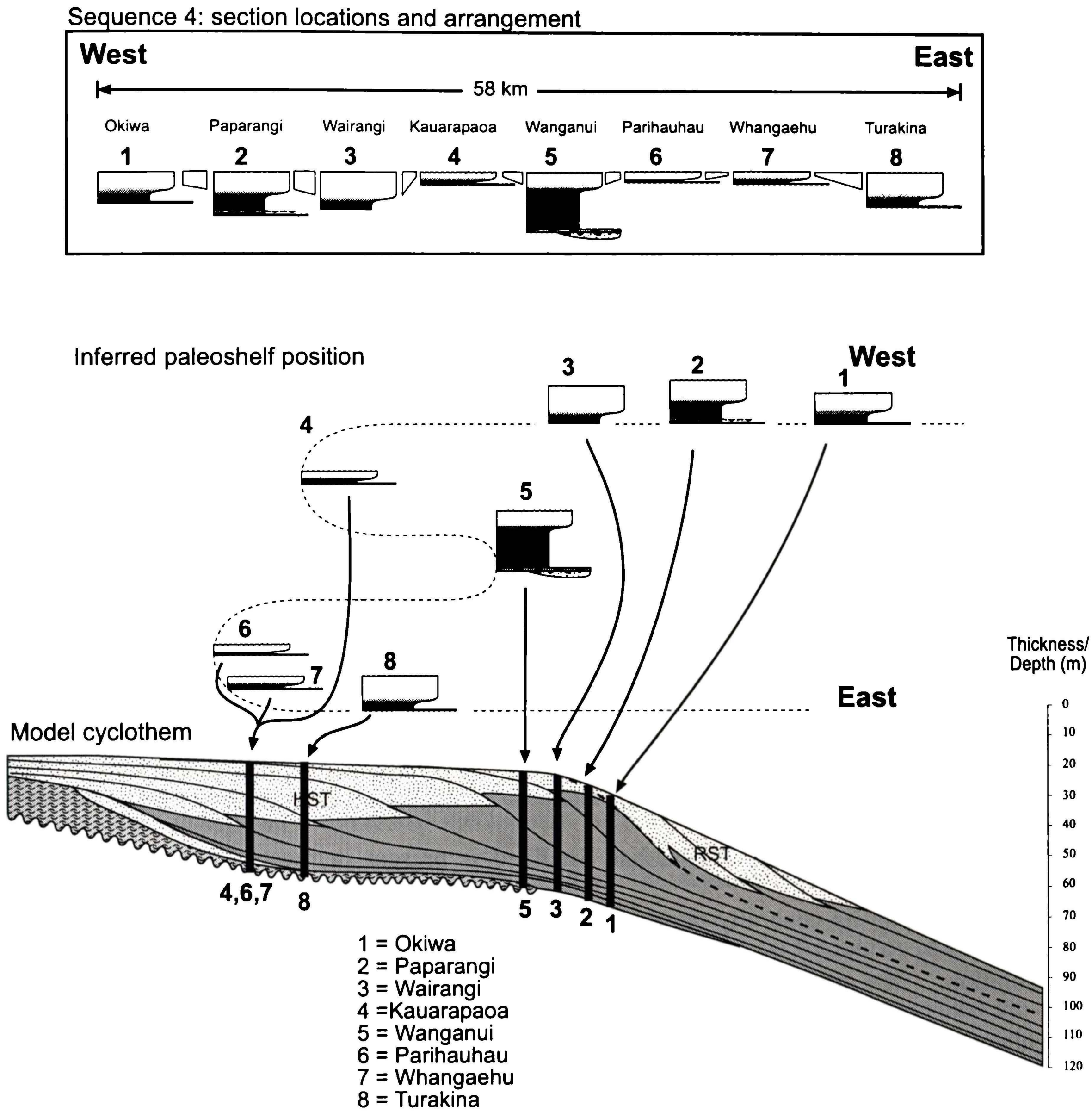


Figure 8.11: Sequence 4, lower Parikino Formation positioned conceptually on model cyclothem. Te Rama Shellbed marks base of sequence.

There, the Te Rama Shellbed unconformably overlies sequence 5, and in places appears to overlie the Caseley Conglomerate, a contact which although not seen directly, is predicted to be an unconformity. The non-marine origin of the Caseley Conglomerate means that it probably accumulated in river channels incised into the exposed paleoshelf during the lowstand between sequences 5 and 4. While the channel itself was probably cut during lowstand, the conglomerate probably accumulated during backfilling of the channel as sea-level rose, ultimately flooding the land surface at this locality. Thus, the Caseley Conglomerate is a TST, as its accumulation occurred in response to marine transgression. One notable feature of the sequence is its great thickness, which means that this locality must have subsided at a greater rate than in adjacent sections. In the Turakina section (8), the Te Rama Shellbed maintains its compound nature and unconformable base. The overall thickness of the sequence here and the ratio of siltstone to sandstone above the shellbed places it on the model cyclothem in a position basinward of its correlative in the Whangaehu (7) section, as shown on figure 8.11. To the east of this locality, the sequence deepens into the Mangaweka Mudstone.

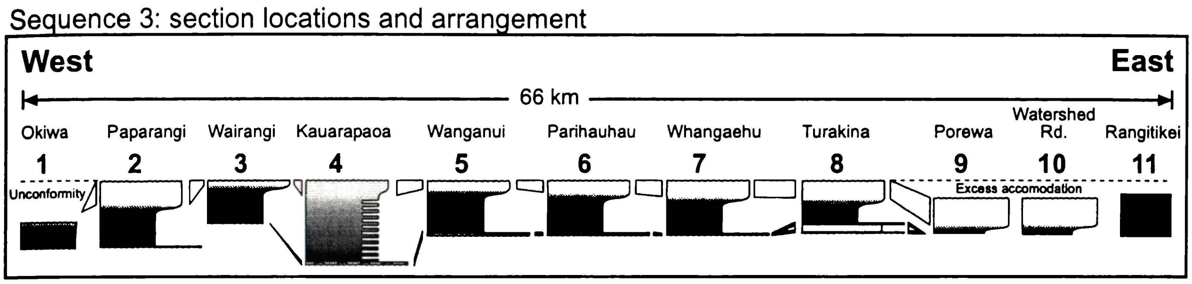
Sequence 2: Middle Parikino Formation, Parihauhau Shellbed: (Figure 8.12)

This sequence maintains a remarkably similar character and thickness across the basin, which implies that the exposed localities mainly accumulated in a similar position on the paleoshelf as illustrated on figure 8.12. The base of the sequence is unconformable across most of the basin, and the Parihauhau Shellbed is present in most of the investigated localities, despite its generally poorly developed nature making it susceptible to meteoric dissolution. One notable feature that has adversely affected the understanding of the architecture of this sequence is the unconformity at the base of the Hautawa Shellbed, which truncates the upper part of the sequence in the Okiwa (1), Paparangi (2) and Wairangi (3) sections. At Okiwa, the Parihauhau Shellbed is not present and may have been leached out of the stratigraphy, but a sharp, burrowed unconformity at the base of the sequence means that the sequence began accumulation in a position shoreward of Point "X", as shown on figure 8.12. No sandstone is present at the top of the sequence, as it is missing in the aforementioned unconformity. The sequence is much more complete at Paparangi (2), with the Parihauhau Shellbed occurring as a poorly developed compound shellbed, and a relatively significant thickness of HST sandstone present in the upper parts of the sequence. However, the basal Nukumaruan unconformity also truncates the top of the sequence here, and thus the original, true thickness of the sandstone is unknown. The available evidence is available evidence is consistent with an inner-mid shelf depositional environment, as predicted by the model cyclothem.

The sequence is very poorly preserved at Wairangi, with both the Parihauhau Shellbed and most of the upper sandstone having been removed from the stratigraphy by dissolution and erosion. However, the thickness of HST siltstone in the sequence closely matches its correlative in the Paparangi section, and thus the two localities probably accumulated in very similar paleoshelf depths and conditions. In Kauarapaoa valley (4), the sequence has an unusual architecture, anomalous compared with all other sequences in the entire Mangapanian succession. The Parihauhau Shellbed is present as a weak, compound shellbed at the base of the sequence, but the textural analysis of the terrigenous material above the shellbed reveals up to nine coarsening-upwards siltstone and sandstone oscillations, which are possibly progradational parasequences. This high-order cyclicity is not present in correlative sequences in adjacent sections, and so its occurrence here is presumably due to an intrabasinal mechanism such as lobe migration of an approaching river delta during aggradation and regression. Were this textural pattern present in adjacent sections, a higher than 6^{th} order extrabasinal mechanism of similar frequency to Dansgaard-Oeschger (2-3 k.y.) cycles could be inferred, but this is unlikely as these cycles are not thought to imply a eustatic sea-level change, and have not been reported in strata older than the late-Pleistocene (Sarnthein *et al.* 2000).

While the model cyclothem does not fully accommodate this unique stratigraphic architecture, the sequence at this locality is positioned centrally on the model, within the compound shellbed + HST part of the paleoshelf, based on its occurrence within an array of sequences of consistent thickness. East of Kauarapaoa valley, the sequence is exposed in the Wanganui (5), Parihauhau (6), Whangaehu (7) and Turakina (8) sections, and maintains a remarkably similar thickness and facies architecture within these four sections. A compound shellbed is present at the unconformable base of the sequence in the Wanganui, Parihauhau and Whangaehu sections, while in the Turakina section the TST is represented by an onlap and backlap shellbed, separated by a 6.5 m thick sandstone SCW.

While the Turakina section contains the most shoreward example of the Parihauhau Shellbed exposed in outcrop, the concordance of thickness of the sequence between this locality and the Wanganui section means that the gradient on the paleoshelf was minimal. This particular example is in close agreement with the facies patterns and thicknesses predicted by the model cyclothem. A marked deepening is inferred to occur within the sequence eastward of the Turakina section, as the Parihauhau Shellbed is not present in the Porewa (9), Watershed Road (10) or Rangitikei (11) sections. In the Porewa and Watershed Road sections, only the upper sandstone can be reasonably confidently correlated with this sequence, as the lower parts of the sequence grade into the Mangaweka Mudstone. Thus, the sandstone present in these sections at this stratigraphic position must be an RST deposit, in much the same manner as sandstone beds observed in sequences 9, 10 and 11. In the Rangitikei section (11), the sequence is only semi-discernible within the Mangaweka Mudstone, and thus is plotted on the extreme basinward part of the model cyclothem. However, the model predicts that while the sequence contains only siltstone, technically it could be crudely subdivided into lower (HST) and upper (RST) parts.



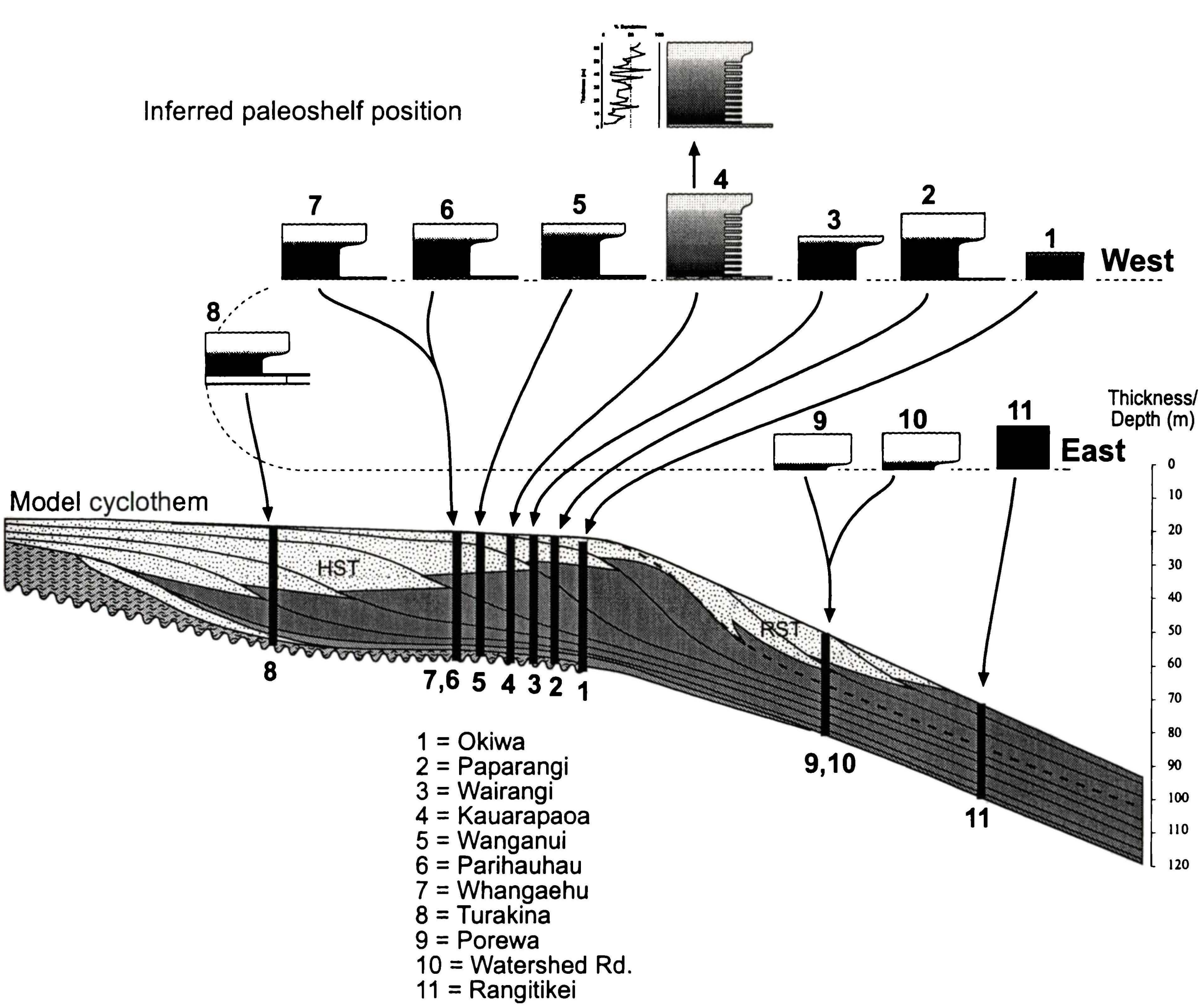


Figure 8.12: Sequence 3, middle Parikino Formation positioned conceptually on model cyclothem. Parihauhau Shellbed marks base of sequence.

Sequence 2: Upper Parikino Formation, School Shellbed: (Figure 8.13)

Sequence 2 represents the youngest Mangapanian strata in Wanganui Basin. Much of the sequence has been truncated in the western parts of the basin. The effects of this truncation can be observed in the relative thickness of the sequence, as the sequence thins progressively west of the Whangaehu section (4), and is not present in the stratigraphy westward of the Kauarapaoa section (1). In the latter section the sequence is only a few metres thick, with an unconformity overlain by a compound shellbed (School Shellbed) at its base. The westernmost occurrence of the School Shellbed is remarkable: it crops out at the top of the Kauarapaoa-Mangaiti watershed at R22/894576, and closely resembles the Wilkies Shellbed. Here, the total thickness of the shellbed is 11 m, and displays almost identical *Crassostrea* biostrome development to the Wilkies Shellbed, which crops out ~ 200 m stratigraphically beneath this locality and can be observed at the base of this hill on the Kauarapaoa Stream banks. As no stratigraphic confusion exists between the two units, it is reasonable to assume that this particular site represents much the same balance of environmental backlap conditions resulting in the accumulation of the Wilkies Shellbed. While *Crassostrea* specimens are common in the upper part of the School Shellbed in the central parts of the basin, the abundance increases gradually from rare in the Turakina section (5) to abundant in the Wanganui (2) and Kauarapaoa (3) sections, but does not reach a thickness of over 1 m. Thus a westwards deepening is inferred for the School Shellbed in the western part of the basin, based on similar trends occurring in the Wilkies Shellbed. A prediction can be made that the School Shellbed probably would have once been a backlap-only *Crassostrea* biostrome somewhere to the west of Kauarapaoa, conformably overlying sequence 3. East of the Kauarapaoa section, the School Shellbed maintains its compound nature into the Wanganui (2) and Parihauhau (3) sections, but separates into an onlap + SCW + backlap TST in the Whangaehu section (4). In the Turakina section (5) many features indicate that of all the observed localities, this locality is the most proximal to a

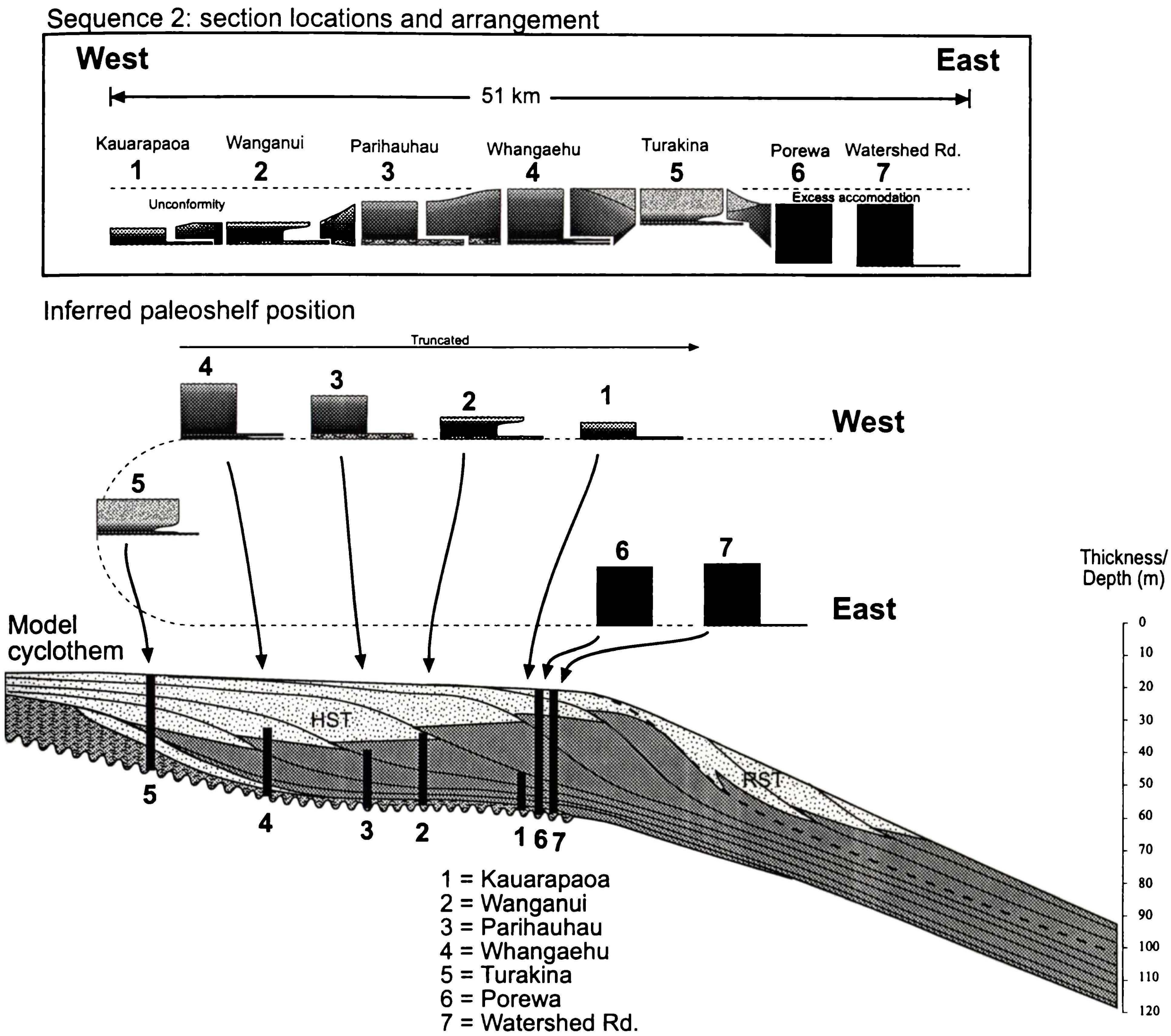


Figure 8.13: Sequence 2, upper Parikino Formation positioned conceptually on model cyclothem. The School Shellbed marks the base of the sequence.

highstand paleoshoreline. Firstly, the School Shellbed is comprised of only a poorly developed onlap part, with ~ 2m of sandstone directly above the shellbed interpreted as a SCW deposit. The absence of a backlap shellbed here means that this locality accumulated in a nearshore to shoreface position on the paleoshelf. Furthermore, the architecture and texture of the terrigenous units above the shellbed are consistent with such a depositional environment, and this pattern of sequence and facies architecture is well accommodated by the model cyclothem, as illustrated on figure 8.13. To the east of the Turakina section, the sequence thickens, and is very fine-grained, with siltstone facies being dominant. In the Watershed Road section (7) a thin, weathered shellbed resting unconformably on sandstone marks the sequence boundary, but the shellbed is too weathered to identify any fossils. However, the model cyclothem predicts that a compound shellbed would be the most likely type of shellbed to occur here, based on the unconformable sequence boundary and the HST siltstone overlying the shellbed. Thus, an increase in water depth is inferred east of the Turakina section (5), and the occurrence of conformity-bound, featureless outer-shelf siltstone (depth from Naish, 1995) cropping out in the equivalent stratigraphic position in the banks of the Rangitikei River indicates proximity to the basin depocentre at this time.

Assessment of model cyclothem, and possible improvements.

The comparisons made between the architecture of sequences in the Mangapanian succession and the model cyclothem help to test the model and identify how the shelf developed across the basin. The sequences on which the model cyclothem are based occur above and below these other sequences, and during an interval when there were probably not major changes in sediment supply, climate and rates of tectonic subsidence and eustatic sea-level change. This study does not make a claim that the model cyclothem can be applied in other basins to determine the paleoshelf position of sequences because of likely differences in the factors controlling baselevel. A limitation of the model cyclothem is the lack of knowledge of facies architecture at the highstand shoreline, and the non-marine coastal plain. Furthermore, the model does not extend to the mid to lower slope or basin floor. Another shortcoming of the model is its inability to deal with the occurrence or non-occurrence of sandstone at the top of the sequence in the vicinity of the HST / RST division boundary.

Cyclicity in the Mangaweka Mudstone, Rangitikei River Section.

Textural patterns within the Mangaweka Mudstone in the Rangitikei River section (Journeaux, 1995) reveal a subtle cyclicity in sediments accumulating in outer slope to upper bathyl water depths. The cyclicity occurs as a gradual increase and decrease of sand content, and since the dominant facies is always siltstone, these textural variations are too subtle to be visible in outcrop. As no unconformity, bedding plane or obvious facies transition marks these cycles, depositional sequence stratigraphy cannot be applied to them (Galloway, 1989). Nevertheless, the textural cycles illustrate one form of sequence architecture in outer shelf to upper slope environments. Journeaux (1995) and Kamp *et al.* (1998), assigned and OIS to each of these cycles, but new data resulting from this study necessitates revision of these assignments. The revision is presented in figure 8.14. The magnetostratigraphy derived from this section constrains the strata to the age range 3.032 to 2.582 Ma, and thus a correlation between the textural cyclicity and the oxygen isotope curve can be made. The LO of the benthic foraminifer *Cibicides molestus* within the Mangaweka Mudstone provides a useful datum, as this bioevent is associated with OIS G11-G10 (see chapter 4). Thus, the oxygen isotope stage chronology that can be applied to the section allows correlation of individual sedimentary cycles within the Mangaweka Mudstone to be made with the sequences within the Paparangi and Okiwa Subgroups.

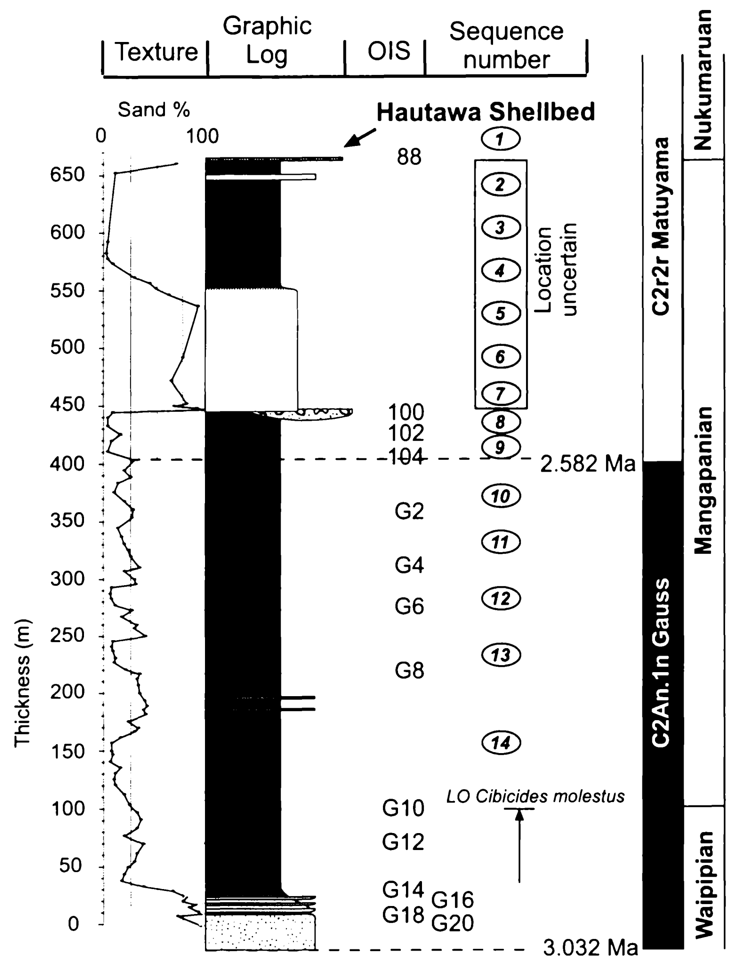


Figure 8.14: Lithology of Mangapanian Stage, Rangitikei River Section. Curve to left of graphic log displays textural variations within Mangaweka Mudstone, and correlations to the Oxygen Isotope Stage are shown to right.

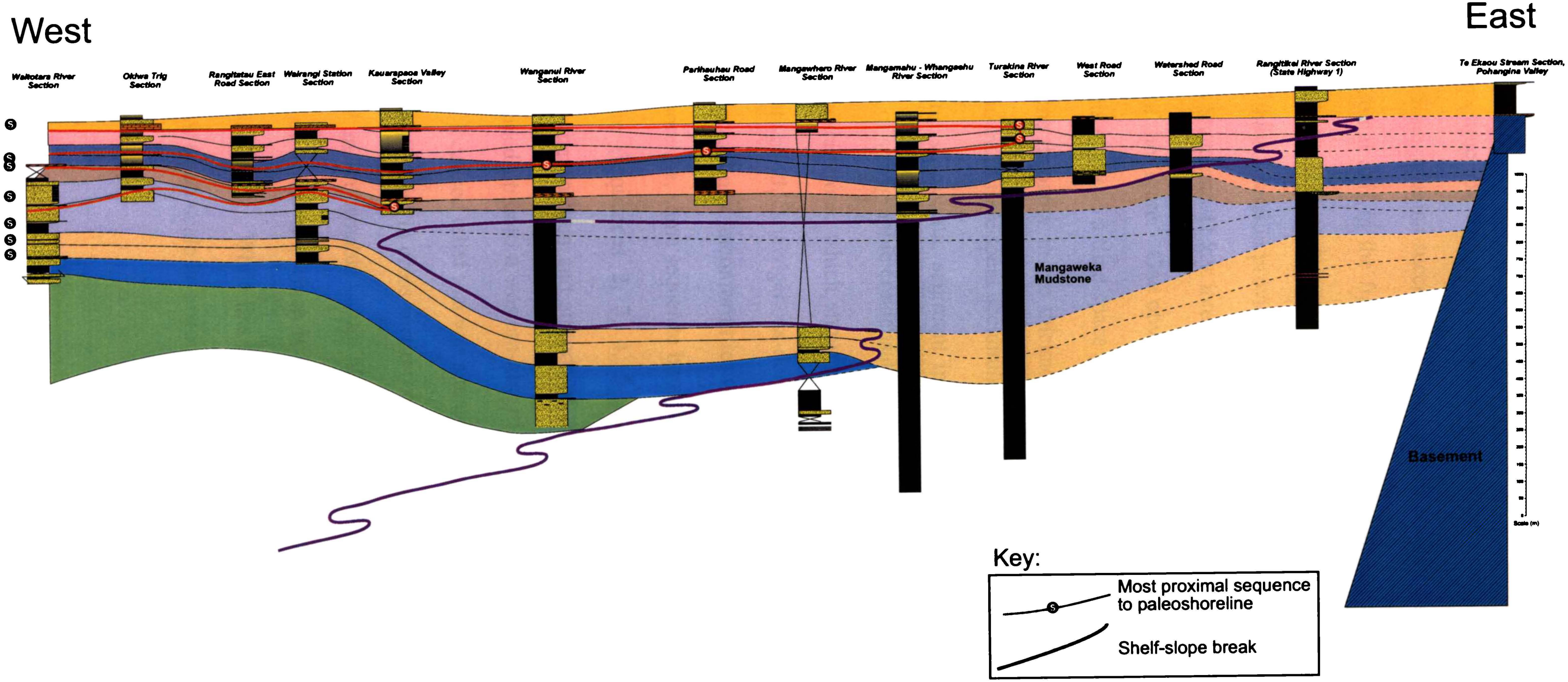
Sequence stacking patterns and paleogeographic implications.

One striking feature of the comparisons of sequence to the model sequence comparisons is that few mirror the linear shoreface-to-basin deepening trend that the three 'basic' sequences exhibit. Instead, they have their nearest shore occurrence in a mid-longitudinal position within the outcrop of the Okiwa Subgroup, and their depth of deposition appears to deepen both eastward and westward from this point. This observation has two implications. Firstly, it means that the sequences will not "stack" in a consistent, linear direction, but are superimposed in multiple directions. This effect can be observed in figure 8.15, which shows how the succession stacks, sequence by sequence. The coloured bands in the figure represent the formations within the Paparangi and Okiwa Subgroups, as depicted on the geologic maps (Enclosure 2). The horizontal, generally parallel lines delineate the sequences, which become dashed when the sequences pass into the monotonous Mangaweka Mudstone, in which they are not obvious. The thick blue line separates the inner mid shelf part of each sequence from the outer shelf to slope siltstone facies, and thus is the shelf edge, as defined by facies. The thick red line punctuated with points marked "S" illustrates the migration of the point of maximum highstand flooding through the succession, with each "S" marking the most shoreward point preserved for each sequence. Where the shallowest point in inferred to occur in a position outside the figure, the "S" is plotted on the edge of the figure closest to the expected highstand paleoshoreline. Comparison of the line drawn between the points of proximity to maximum highstand flooding (red) with the line marking the shelf-edge break (blue) reveals that the two lines are generally parallel. One obvious feature on the figure is the westward deflection of the shelf-edge break in the central parts of the basin in early-mid Mangapanian time associated with the accumulation of the Mangaweka Mudstone. This feature is almost certainly due to an abrupt and localised tectonic "pull-down", as shown by the similar thickness of the Mangaweka Mudstone in the central basin, and the down-warp of the Whenuakura and

Paparangi Subgroup sequences in the western part of the basin. While this down-warp appears to have produced a monocline in the western part of the basin, correlation of the sequence boundaries into the Mangaweka Mudstone in the Rangitikei River Section (see above) reveals that this structure is possibly a graben, as the time lines deflect upwards into this section.

In the Okiwa Subgroup, the eastward migration of both the point of maximum highstand flooding and the shelf-break means that the Okiwa paleoshelf did not necessarily become wider through time, because if the shelf was to widen substantially, a divergence of these two points would be expected. A likely explanation for the eastward migration of both these features within the group is a change in position of the paleoshelf from an along-strike perspective in the Paparangi Subgroup, to either an up- or down-dip perspective in the Okiwa Subgroup, from a northwards facing viewpoint. This change in the nature of the outcrop belt in relation to the geometry of the paleoshelf is expanded upon in the following chapter.

Figure 8.15: (facing page) Late Waipipian to Early Nukumaruan strata, Wanganui Basin, subdivided both into formational lithostratigraphy (coloured bands) and sequences (horizontal lines). Shelfal sequences are delineated as solid lines, and their deep water correlatives are marked by dashed lines in the Mangaweka Mudstone. The solid blue line marks the shelf-slope break, and the red line traces the position within each sequence most proximal to the contemporary paleoshoreline. Horizontal distance = 103 km, VE = 25.

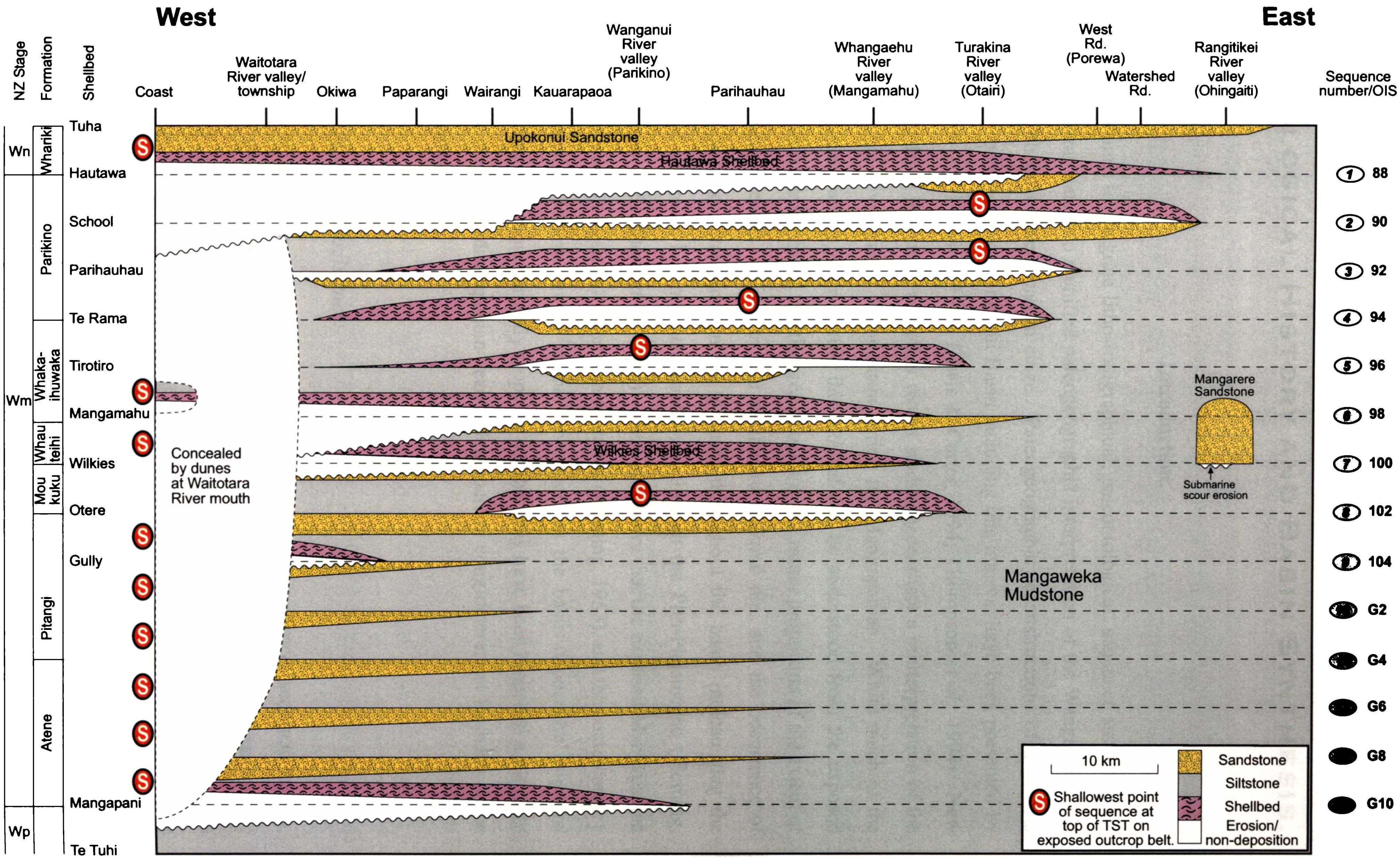


West
East
Waitotara River Section
Okiwa Trig Section
Rangitatau East Road Section
Wairangi Station Section
Kauarapaoa Valley Section
Wanganui River Section
Parihauhau Road Section
Mangawhero River Section
Mangamahu - Whangaehu River Section
Turakina River Section
West Road Section
Watershed Road Section
Rangitikei River Section (State Highway 1)
Te Ekaou Stream Section, Pohangina Valley
Mangaweka Mudstone
Basement
Scale (m)
Key:
Most proximal sequence to paleoshoreline
Shelf-slope break

Chronostratigraphic interpretation:

Figure 8.16 shows time-space relations between facies and contact surfaces for strata in the Wanganui Basin Mangapanian succession. The sections studied are arrayed from west to east on the horizontal axis of the figure, with the relative distance between the sections spaced accordingly to scale. As previously demonstrated in Chapter 4, the sequences occurring within the succession provide a useful means of allostratigraphic subdivision of the Mangapanian Stage into 41 k.y. intervals, which are used as the basic interval of time on the vertical axis of the figure. One obvious difference between displaying the succession investigated in this study as a time-space panel (Figure 8.16) and a thickness-space panel (Figure 8.15) is the disparity in the thickness of shellbed facies. The time-space figure shows that the amount of time spent accumulating carbonate facies is generally equal to that spent accumulating siliciclastic sediment in the shelfal sequences. Thus, the shellbeds represent periods of stratigraphic condensation, an observation not immediately obvious in thickness-space correlations, which show a large asymmetry between the relatively thin shellbeds and relatively thick terrigenous-dominated units, as observed in outcrop. Another key feature is the position of unconformities within the succession; while most are hinged to a western paleoshoreline, some sequence boundaries are only unconformable in the central parts of the basin (sequences 2, 3, 4, 5 and 8). This pattern implies significant rearrangements in the position and attitude of the paleoshelf through this interval. Some transgressions ramped up onto a western-hinged, eastward-dipping paleoshelf, and others flooded an area of localised relief that was situated in the central parts of the basin. Plotting Point "S" (shallowest point in cross-section) on this figure shows the consistency between the conformable / unconformable nature of the sequence boundaries and facies compared with the position of Point "S", which is largely based on the shellbed type and sequence architecture of a sequence. While this supports the validity of Point "S", it also provides further evidence for small-scale inversion of the basin during this interval.

Figure 8.16: (facing page) Time-space facies relations in the Mangapanian succession, Wanganui Basin. The succession is subdivided into 41 k.y. intervals which reflect the control of eustatic cyclicity on facies deposition. Note that not all sequences are hinged to a western paleoshoreline, as reflected in the position of Point "S".


West
East
NZ Stage
Formation
Shellbed
Coast
Waitotara River valley/ township
Okiwa
Paparangi
Wairangi
Kauarapaoa
Wanganui River valley (Parikino)
Parihauhau
Whangaehu River valley (Mangamahu)
Turakina River valley (Otairi)
West Rd. (Porewa)
Watershed Rd.
Rangitikei River valley (Ohingaiti)
Sequence number/OIS
Wn
Wm
Wp
Whariki
Parikino
Whaka-ihuwaka
Whau teihi
Mou kuku
Pitangi
Atene
Tuha
Hautawa
School
Parihauhau
Te Rama
Tirotiro
Mangamahu
Wilkies
Otere
Gully
Mangapani
Te Tuhi
Upokonui Sandstone
Hautawa Shellbed
Wilkies Shellbed
Concealed by dunes at Waitotara River mouth
Mangarere Sandstone
Submarine scour erosion
Mangaweka Mudstone
1 88
2 90
3 92
4 94
5 96
6 98
7 100
8 102
9 104
G2
G4
G6
G8
G10
10 km
Shallowest point of sequence at top of TST on exposed outcrop belt.
Sandstone
Siltstone
Shellbed
Erosion/ non-deposition

CHAPTER NINE:

GEOLOGICAL HISTORY AND BASIN SYNTHESIS.

Introduction.

This chapter aims to integrate lithostratigraphical, paleontological, sequence stratigraphic, well and seismic data into a unified paleogeographic interpretation of the Wanganui Basin for the late Pliocene Mangapanian stage. Paleogeographic reconstructions of a general nature, some peripheral to Wanganui Basin including this interval have been presented by other workers (e.g. Fleming, 1953; Lewis & Carter, 1994; Thompson *et al.,* 1994). New data resulting from this study and other recent studies necessitate a reinterpretation of the paleogeographic development of the basin during the Mangapanian. While much of the geological history of the basin during this interval can be understood from the exposed strata, it has to be remembered that the area of outcrop is a minor proportion of the extent of the Mangapanian record. However, the southward regional dip, and the occurrence of successively younger strata from north to south throughout the basin indicate that the depocentre of the basin has migrated southward through the Plio-Pleistocene (Fleming, 1953; Anderton, 1981; Stern *et al.,* 1993). Thus, it follows that the exposed Mangapanian strata accumulated on a generally northern shoreline (Fleming, 1953), and the contemporary southern shoreline became buried in the subsurface, as the basin depocentre migrated southward. The only strata currently cropping out that may have been hinged to a southern shoreline are the latest Mangapanian– early Nukumaruan conglomerate at Komako in the Pohangina valley.

Sequence Stratigraphic assistance:

Assuming a relatively constant interplay between tectonic subsidence, sediment supply, eustatic sea-level change and climate during Mangapanian time, comparison of Mangapanian sequences to the model cyclothem (previous chapter) allows an approximation of depositional paleoshelf position to be made. As demonstrated in that chapter, such changes in sequence architecture permit interpretation of correlative sequences in a paleogeographic sense, which reveals both shallowing and deepening trends, and the most proximal part of a sequence to the contemporary paleoshoreline (Point "S") to be identified. This identification (Figures 8.15 & 8.16) suggests that the shallowest part migrated between successive sequences from being in a western (presumably onlapping the Patea-Tongaporutu High) to a northern position, as the basin depocentre moved southward. Within the Okiwa Subgroup, the shallowest part of a sequence (Point "S") migrated between the Patea-Tongaporutu High to the longitude of the Wanganui section, the Parihauhau section and finally the Turakina section within the last four sequences of the Mangapanian Stage. This is summarised in figure 9.1, which is a simplified version of figure 8.16, and shows relative deepening and shallowing trends for each sequence. One point of note is that an easterly deflection of Point "S" precedes both the Wilkies and Hautawa Shellbeds, which both exhibit a strong deepening from west to east. This pattern implies that two subtle arrangements of the paleoshelf occurred, one at mid-Mangapanian time, and the other at the Mangapanian / Nukumaruan Stage boundary.

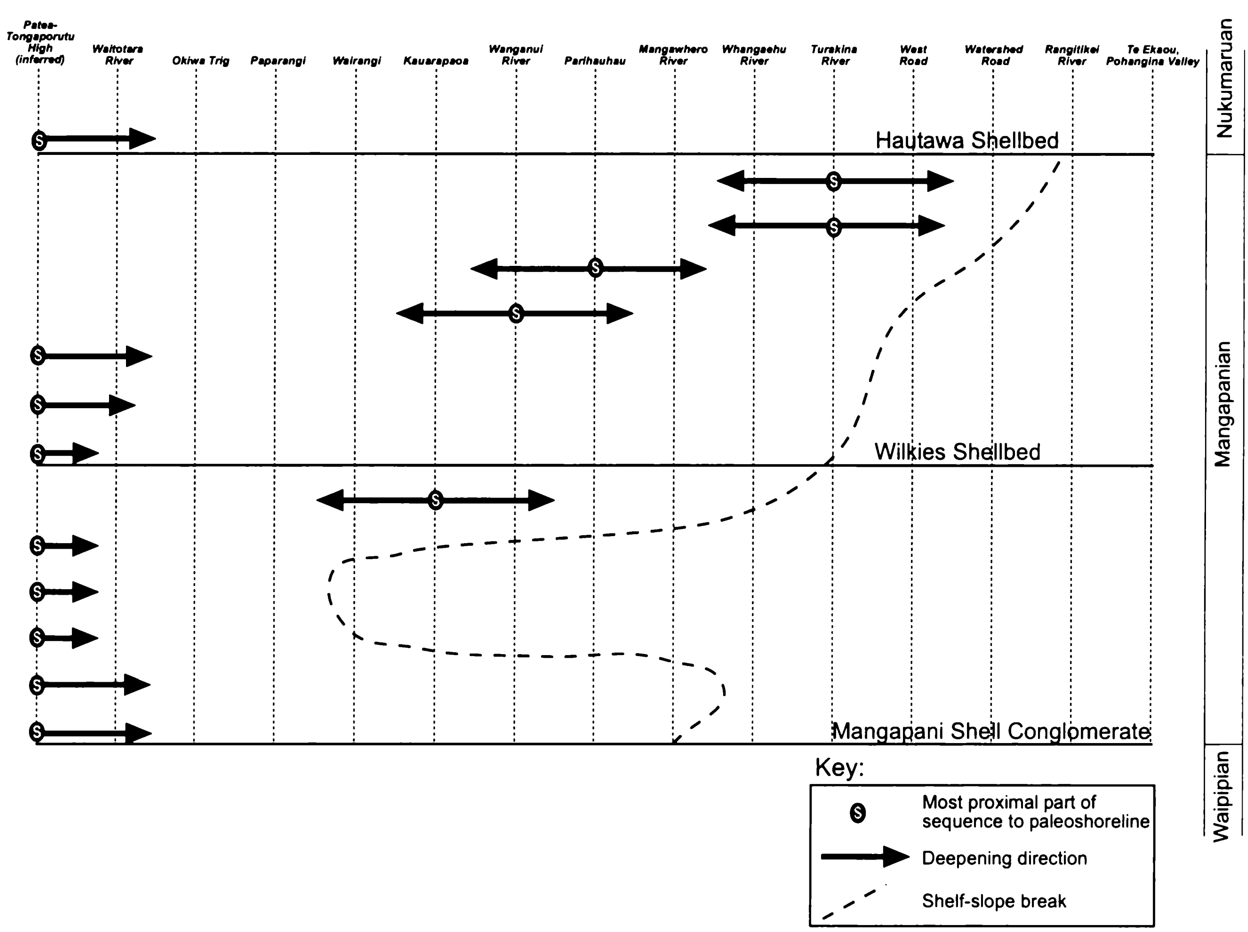


Figure 9.1: Conceptual time-space diagram showing deepening directions away from shallowest point "S" for each sequence within the Mangapanian Stage. The main trend from proximity to a predominantly western shoreline on the Patea-Tongaporutu High to a northern shoreline occurs within the late Mangapanian, with the Turakina High becoming established for the last ~80 ka of the Stage. No horizontal scale implied.

The eastward migration of Point "S" from the Patea-Tongaporutu High to the more central parts of the basin is accompanied by subsidence on the Patea-Tongaporutu High, meaning that the mechanism which caused the central parts of the basin to shallow was possibly linked to vertical motion of the Patea-Tongaporutu High. Such a pattern implies regional tectonic as opposed to sedimentological influences. For example, shallowing in the central parts of the basin could be explained by growth of a delta on the northern paleoshoreline. However, this is most unlikely, as it fails to account for the concomitant development of greater depth of deposition in the west. The less subtle deepening inferred to have occurred during the early Mangapanian from the Mangapani Shell Conglomerate sequence to the mid-outer shelf sequences at the top of the Atene Formation and then into the outer-shelf and deeper Mangaweka Mudstone is a more gradual trend, but demonstrates that significant tectonic influences were occurring during this interval.

Seismic reflection profiles.

Over 15 seismic reflection surveys have been conducted in Wanganui Basin (Anderton, 1981; Uruski, 1998) and thus the subsurface geology of both the onshore and offshore parts of the basin are reasonably well understood. Three seismic profiles (M-118, EA-2, BM-1) have been selected from Enclosure 3 of Kamp *et al.* (in prep) to display the general geometry and structure of the offshore basin fill. The interpretation of the profiles is from Uruski (1998), and the locations of these lines within the basin are illustrated in figure 9.2. These three seismic profiles represent only a subset of the available seismic profiles for Wanganui Basin, but nevertheless display most of the key subsurface features and geometry.

BM-1: (Figure 9.3)

Line BM-1 is a 24-fold offshore line shot for Bounty Oil in 1970 (Uruski, 1998), and runs parallel to the shoreline of Wanganui Bight, curving gently southwards from ~ 3 km offshore from the Whangaehu River mouth to the latitude of Levin (figure 9.2). The proximity of this line to the Whangaehu-1 and Santoft-1A wells allows subdivision of the reflection horizons, with the Mangapanian Stage strata being the central, light pink layer on the interpreted profile. This profile shows how the Mangapanian strata onlap Mesozoic Basement (Torlesse Schist, Mortimer *et al.,* 1997) to the south, defining the southern basin margin for this interval. The projected positions of Whangaehu-1 and Santoft-1A are also displayed on the interpreted profile, and one point of note is that the latter well is situated above an antiform structure, bounded by high-angle reverse faults. This structure is named the "Turakina High" for the purposes of this study, as the Turakina Fault System (Anderton, 1981) delineates the western edge of the upthrust block. The majority of faults on this profile are reverse, and are rooted in the basement geology. Thus, the basin has experienced significant compression late in its history, with several prominent structural highs developing.

M118: (Figure 9.4)

Line M118 is a 24-fold offshore line shot for Mobil in 1971 (Uruski, 1998), and lies on a bearing of ~ 120 ° NW-SE across the basin, with the southeastern end of the line about 10 km offshore from the Turakina River mouth (Figure 9.2). The proximity of this end of the line to profile BM-1 allows stratigraphic reflector horizons to be transferred from that line into M118. The Turakina High occurs in this part of the profile, and the strata dip gently between the Patea-Tongaporutu and Turakina Highs. The Turakina Fault system displaces the Cenozoic strata in a reverse sense on to the Turakina High. To the northwest, the Mangapanian strata thin and onlap Waipipian strata on the Patea-Tongaporutu High, where they are truncated by Nukumaruan strata, presumably the same truncation of Mangapanian strata as seen in outcrop. While high-angle reverse thrust faults within the basement geology provide evidence for crustal shortening, minor normal faults of the Nukumaru Fault Zone occur on the eastern flank of the Patea-Tongaporutu High.

EA-2 (Figure 9.5)

Shot for Esso Petroleum in 1967 (Uruski, 1998), line EA-2 is a single-fold migration profile bearing NE-SW at an angle perpendicular to line M118. Over 110 km in length, this offshore line is one of the longest in the basin, and extends from the latitude of Wanganui City southwards to the latitude of Kapiti Island (Figure 9.2). This profile shows the southward onlap on to basement of progressively younger strata, followed by regional downwarp of the basin during Castlecliffian time. While small reverse faults occur within the basement rocks, the succession is largely unfaulted. This is due to the profile paralleling the compressional anti- and synform structures, and to its lying between the Patea-Tongaporutu and Turakina Highs. Thus, this profile lies within a NE-SW trending sub-basin and represents the north to south downwarp of the basin throughout the Plio-

Pleistocene. The crustal shortening observed in other seismic profiles occurred at an angle generally perpendicular to the bearing of this profile.

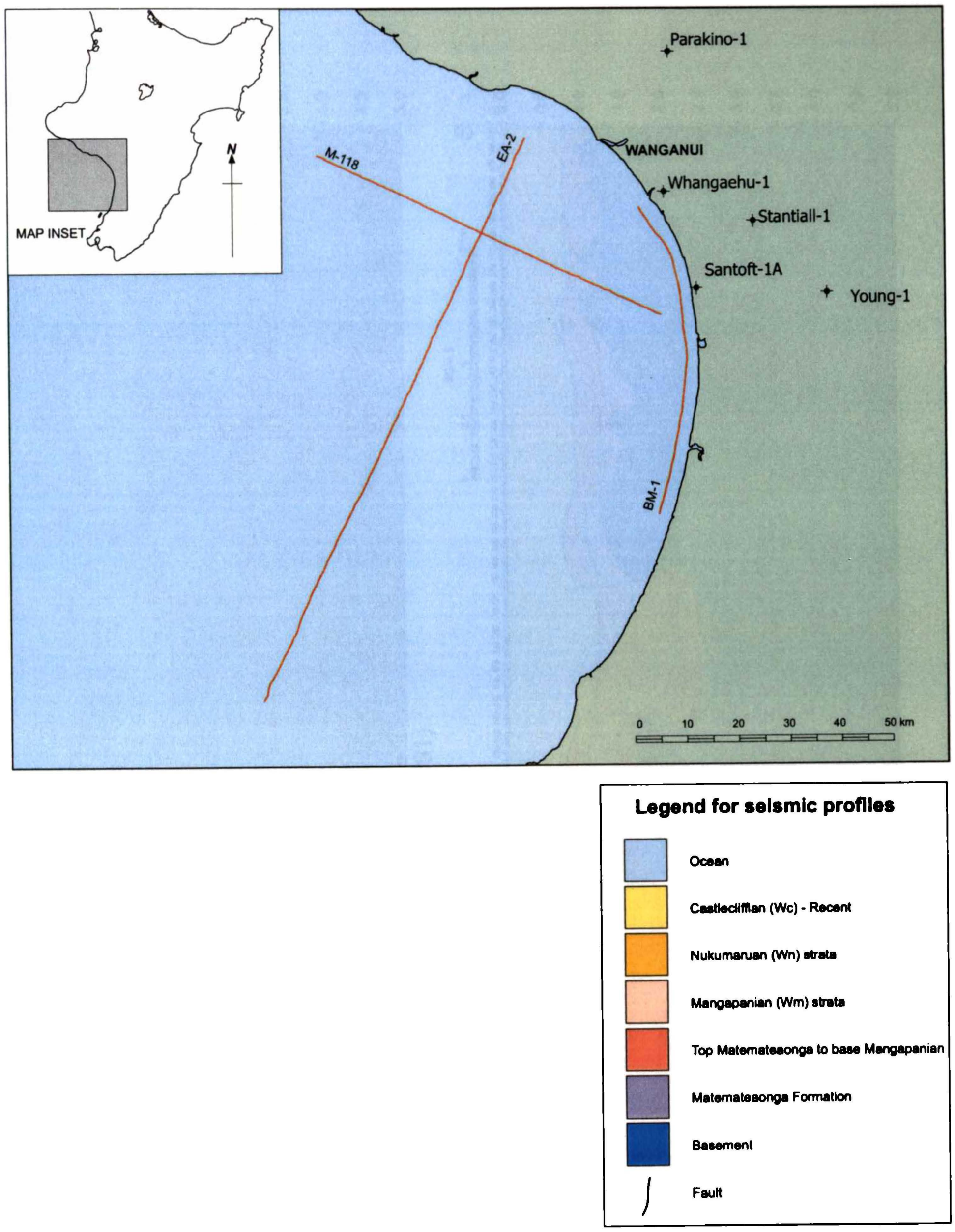


Figure 9.2: Map showing location of the three seismic lines BM-1, M118 and EA-2. (after Kamp *et al.* (in prep))

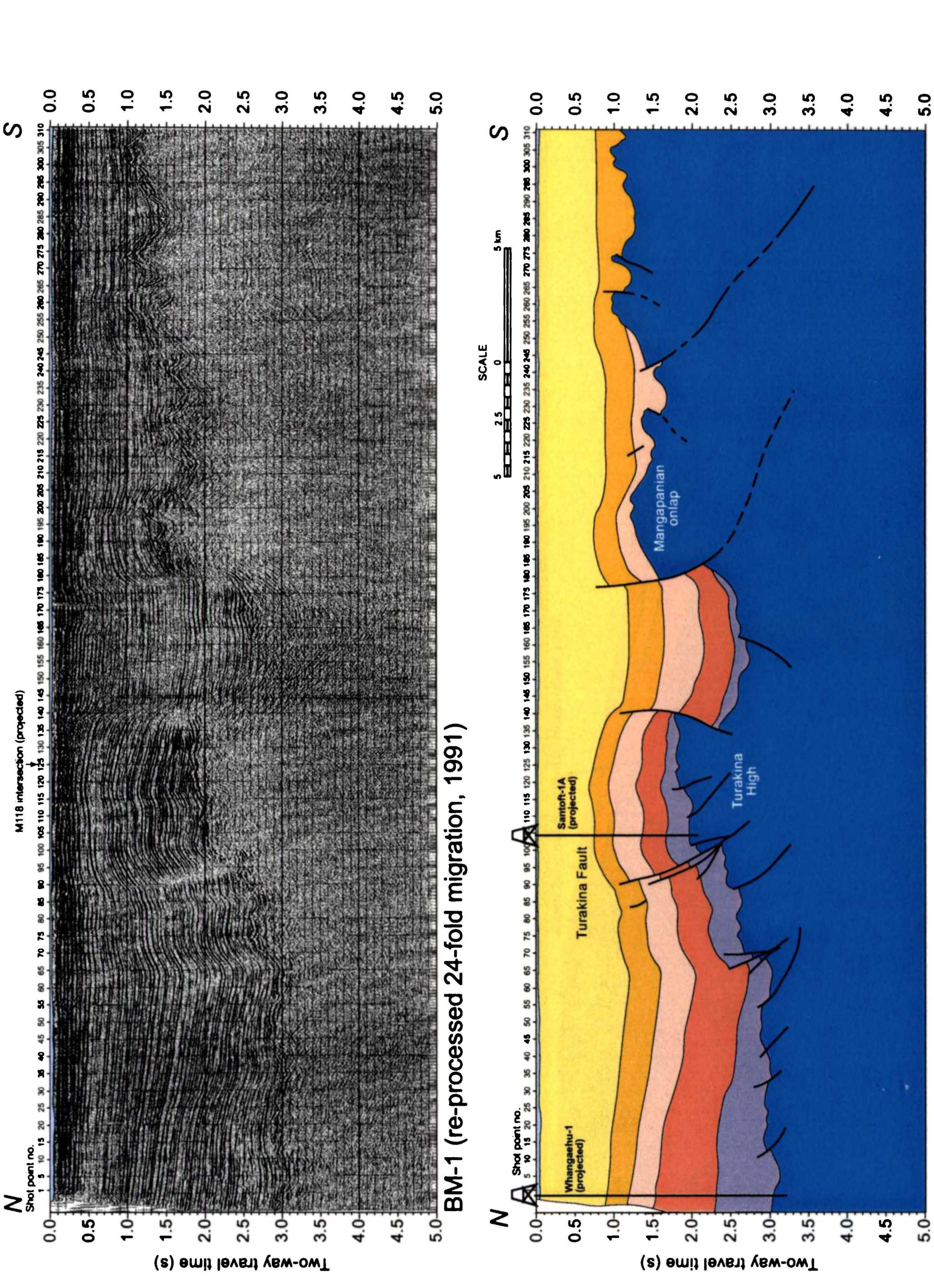


Figure 9.3: Line BM-1 showing extensive antiform and synform development in central-eastern Wanganui Basin. (after Kamp *et al.* (in prep)).

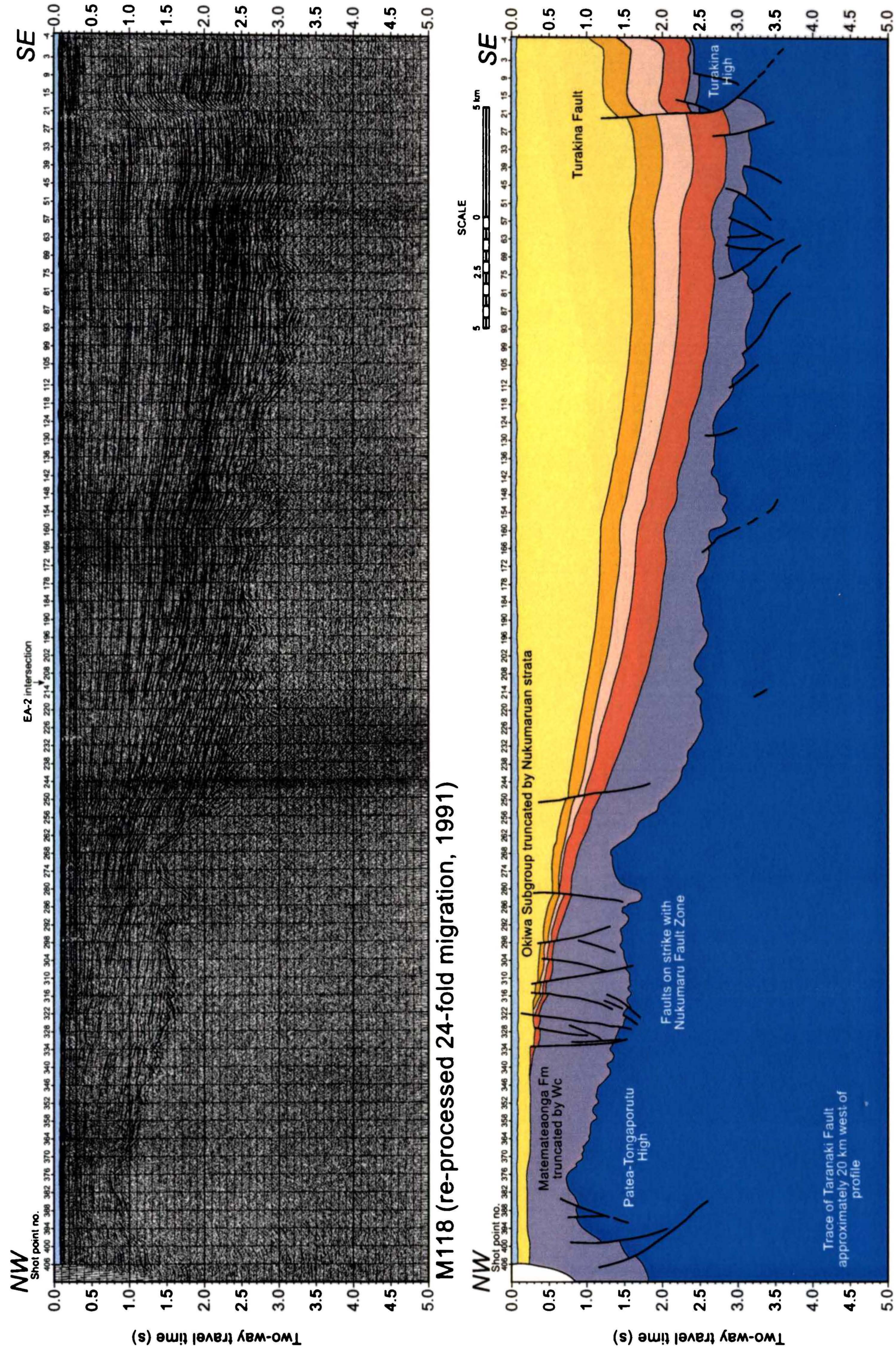


Figure 9.4: Line M118 showing westward onlap and truncation of Plio-Pleistocene strata onto Patea-Tongaporutu High. (after Kamp *et al.* (in prep)).

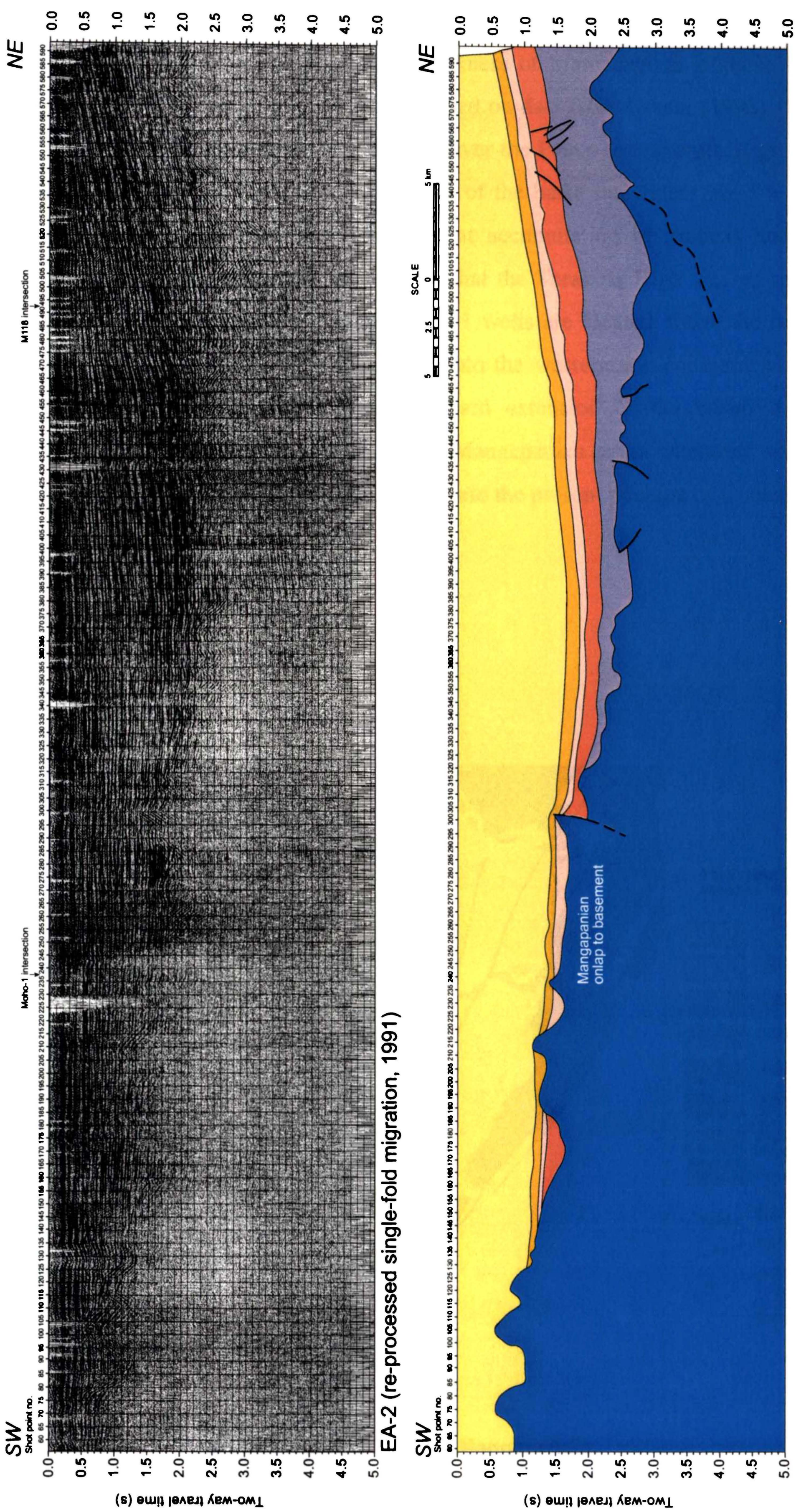


Figure 9.5: Line EA-2 showing progressive southward onlap of Plio-Pleistocene strata on Mesozoic basement. Note relative lack of faulting.(after Kamp *et al.* (in prep)).

Isopach Map.

Figure 9.6 is an isopach map showing the thickness of Mangapanian strata in the basin subcrop, and is from Kamp *et al.* (in prep.), based on data from Uruski (1998). The map clearly shows that Mangapanian strata do not cover the Patea-Tongaporutu High, and that active fault systems partitioned the eastern part of the basin into linear NE-SW trending blocks, with the greatest thickness of sediment accumulating in grabens bounded by reversely faulted paleohighs. The map shows that the Turakina High was present in the Mangapanian, and the Santoft-1A and Stantiall-1 wells are located above the high. The horst and graben topography does not extend into the western and southern parts of the basin during the Mangapanian. The southward extension of the basin in the late Mangapanian is apparent, with a long lobe of Mangapanian strata extending southwards past the present day extent of Kapiti Island, and into the present position of Cook Strait.

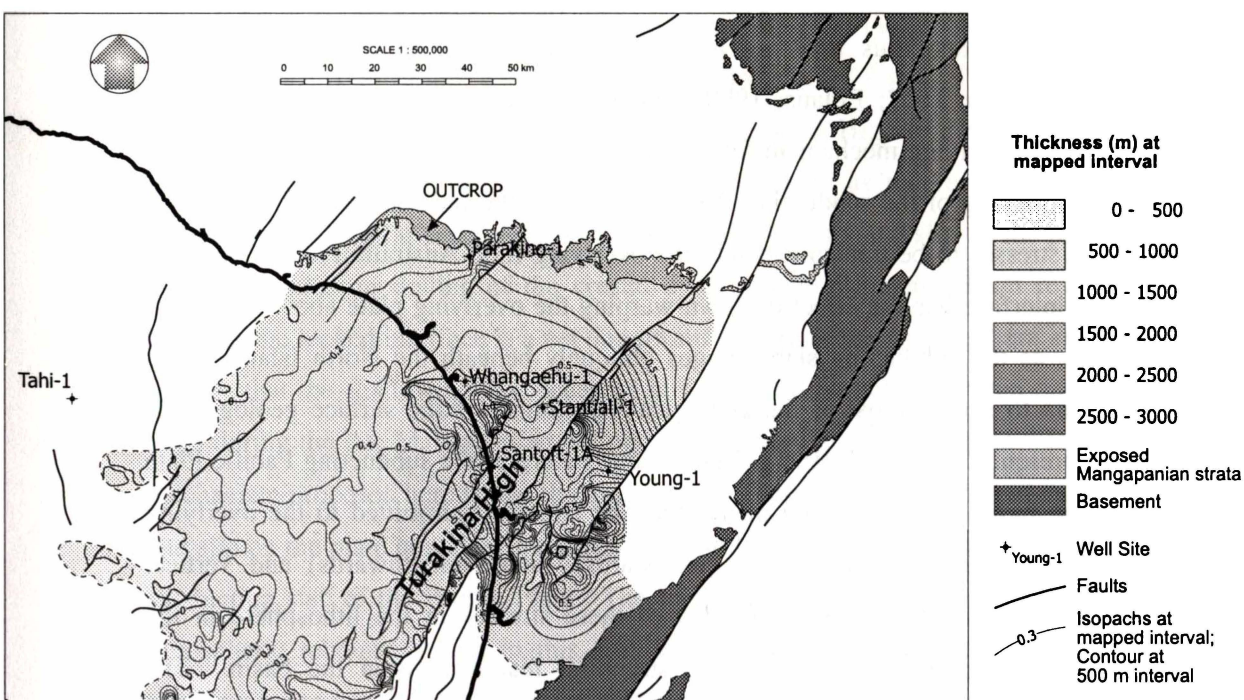


Figure 9.6: Isopach map for Mangapanian strata in Wangauni Basin subcrop. (after Kamp *et al.* (in prep.)) Scale = 1:1,000,000

Tectonic mechanisms.

Stern *et al.* (1993) demonstrated that the large thickness of sediments within the Wanganui Basin could not be attributed solely to sediment loading, but that the primary driving mechanism for basin subsidence was tectonic, and this process was amplified by sediment loading to constitute the total driving load for the basin. Katz & Leask (1990) proposed large-scale thrust loading on steeply dipping reverse faults somewhere to the east of the basin as a driving mechanism for basin subsidence, which would thus classify the Wanganui Basin as a fore-deep structure. However, the lack of gravity anomalies associated with these reverse faults means that the amount of thrust loading is insufficient as a mechanism for basin development (Stern *et al.,* 1993). The possibility of the Wanganui Basin being an extensional feature linked to the rifting in the Taupo Volcanic Zone is an alternative hypothesis, but this scenario is inconsistent with the presence of reverse faults in eastern parts of the basin. While normal faulting is present in the western parts of the basin (e.g. Nukumaru Fault Zone, Upokongaro Fault), these faults are probably the result of displacement to accommodate lithospheric flexure of Cenozoic strata mantling young, growing anticlines, and thus may not be directly linked to large-scale basin-forming processes (Te Punga, 1957; Pillans, 1990). Geodetic studies by Walcott (1978; 1987) suggested that the driving mechanism for the subsidence resulting in the Wanganui Basin was linked to locking of the subducting Pacific Plate with the Indo-Australia Plate, which allows shear stresses to be transmitted into the overlying Indo-Australia Plate. Thus, the locked plate interface has the effect of down-warping the overlying plate above this high-friction zone, as the subducting slab plunges obliquely beneath the North Island. This theory appears to satisfy most of the geological constraints of the surface geology, and accepted at present (Stern *et al.* 1993). The oblique nature of the subducting Pacific Plate relative to the Indo-Australian Plate means that the stresses transmitted to the overlying plate can be separated into horizontal (westwards), lateral (southwards) and vertical (downwards) components, and the interplay of these stresses in the lithosphere in the Wanganui Basin region explains the basic structural features within the basin. The southward migration of the Wanganui Basin itself is due to the effect of the southern component of movement on the locked plate interface, as the crust is pulled vertically downward and laterally southward in a dextral sense. The effects of the horizontal component of stress (lateral transpression) is manifested in the rocks as reverse-faulted antiform and synform structures in the eastern part of the basin, but the submergence of these structures during Mangapanian time means that a downward-directed vertical stress component was also present. Furthermore, the dextral strike-slip nature of the faults (e.g. Rangitikei Fault, Rauoterangi Fault) in this part of the basin infers the presence of a lateral stress component. However, the rarity of compressional antiform structures in Mangapanian rocks in the large, relatively undeformed SW part of the basin implies that much of the horizontal stress component was accommodated by the crustal shortening expressed as alternating anti- and synforms in eastern Wanganui Basin (e.g. Turakina High) so that the region between the Patea-Tongaporutu and Turakina Highs displays relatively little reverse faulting. In Wanganui Basin, the presence of the Patea-Tongaporutu High and vertical movement on it, implies the occurrence of a persistent stress component acting across the basin, but the amount of crustal shortening associated with this structure is less than the amounts associated with the large-scale block faulting in the eastern parts of the basin (Figure 9.4, line M118). With the locked Taranaki Fault acting as a backstop buttress on the western basin margin, the Patea-Tongaporutu High can be viewed as a fore-bulge, with enough relief to separate the Taranaki and Wanganui Basins while a west-directed stress component was present.

While the Pacific/Indo-Australian plate interface beneath the North Island is locked on at least a century timescale, Walcott (1978; 1987) and Stern *et al.* (1993) allude to the likelihood of slip on the subducting thrust, over significantly longer (geological) timescales. This inference is consistent with the pattern of relocation of Point "S", as described above. The relocation of Point "S" from the Patea-Tongaporutu High to a more eastern position within the basin in the late Mangapanian is interpreted as the result of a minor basin inversion; that is, a far-field effect resulting from unlocking and slip on the plate interface. While computer modelling of the crustal dynamics in Wanganui Basin reveals that the effect of the locked interface is a net downward flexure of the region (Stern *et al.,* 1993), it follows that the shallowing that occurred in the central parts of the basin on the Turakina High during the late Mangapanian did not occur while the plate interface was locked. The mechanism proposed here is that the growth of the Turakina High occurred from unlocking and slip on the plate boundary interface, which released the Indo-Australian Plate from the subducting slab of the Pacific Plate. The release of the vertical stress component caused lithospheric rebound, which in this case was greatest in the central parts of the basin, resulting in the growth of the Turakina High. The concomitant release of the west-directed horizontal stress component concentrated on the basin margins caused the Patea-Tongaporutu High to subside, thus inverting the basin and reversing the slope of the paleoshelf in the western part of Wanganui Basin. Subsequent re-locking of the plate interface at end Mangapanian time allowed downward lithospheric flexure to resume, thus re-creating the normal basin profile. This process is conceptually illustrated in Figure 9.7, which shows a schematic profile of the basin during a period of downwarp and transpression resulting from stresses originating from relative plate motion and transmitted to the lithosphere overlying the locked plate interface. This process alternates with relaxation and inversion resulting from unlocking and slip on the plate interface. This observation also implies that the direction in which the stress release was directed was easterly, as the Taranaki Fault (an alternative candidate for a release plane) was largely locked during this interval. An earlier, smaller slip episode is inferred to have occurred within mid-Mangapanian times, with the easterly deflection of Point "S" within the Moukuku Formation (Otere Shellbed) to the vicinity of the Kauarapaoa valley followed by retreat of Point "S" back to the Patea-Tongaporutu High in the following sequence.

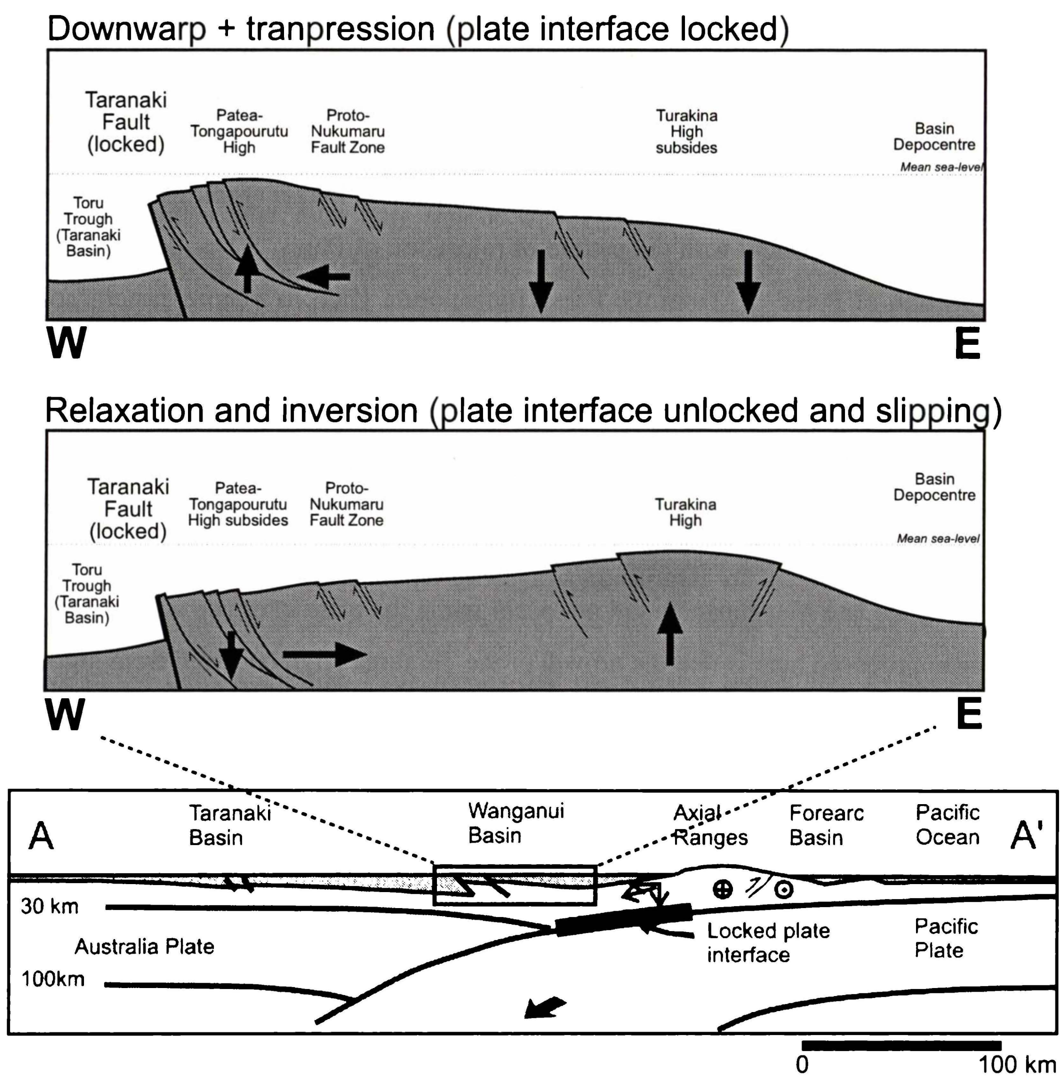


Figure 9.7: Driving tectonic mechanism for basin formation (lower window) on locked plate interface, and inferred structural response to downwarp (upper window) and relaxation from slip on the locked plate interface (middle window). Basement surface is schematic only.

The above hypothesis assumes no lag between events on the plate boundary interface and the resulting lithospheric and sedimentary response. Thus, strata hinged to a western paleoshoreline (Patea-Tongaporutu High) are considered to have accumulated in an interval in which the plate interface was locked, and strata not hinged to the Patea-Tongaporutu High are considered to have been deposited when the plate interface was unlocked and the two plates could slip past each other. Thus, the Mangapanian Stage in Wanganui Basin can be subdivided into locked and unlocked time intervals. Strata at the base of the stage appear to be hinged to the Patea-Tongaporutu High, suggesting that they accumulated during a period of subsidence resulting from a locked plate boundary. Little is known about the late Waipipian Stage strata underlying the Mangapani Shell Conglomerate, and so it cannot be determined when the interval of locking inferred at this early Mangapanian time commenced. However, all strata between the base of the Mangapani Shell Conglomerate (2.79 Ma, OIS G10) and the base of the Otere Shellbed (2.55 Ma, OIS 102) accumulated while the plate boundary was locked, an interval of 240 k.y.. The first unlocking occurred at 2.55 Ma (co-eval with the base of the Otere Shellbed, OIS 102) and remained so for approximately 20 k.y., as a re-locking of the plate interface in inferred from the Makokako Sandstone being hinged to a western paleoshoreline (Figure 8.16, Chapter 8). A sustained interval of subsidence in the central parts of the basin following re-locking of the plate interface occurred between 2.53 and 2.46 Ma (base of Makokako Sandstone (OIS 101), to top of Mangamahu Shellbed (OIS 97), an interval of 70 k.y. The largest and longest period during the Mangapanian Stage in which the plate interface unlocked and remained so was from the top of the Mangamahu Shellbed (2.46 Ma, OIS 97) to the base of the Hautawa Shellbed (2.28Ma, OIS 88), an interval of 180 k.y. Thus, during the ~ 0.5 M.y. Mangapanian Stage, the total time for which the plate interface was locked was 310 k.y., and it was unlocked and slipping for 200 k.y.

The increase in depth of deposition that resulted in the accumulation of the outer-shelf to upper slope Mangaweka Mudstone (Wanganui River valley) is interpreted here as representing a sudden acceleration in the rate of tectonic subsidence. The timing of this event is consistent with the above interpretation of a locked plate interface driving lithospheric downwarp at this time, but the reason for this sudden acceleration in subsidence rate is unknown.

Paleogeographic maps.

Early Mangapanian:

Figure 9.8 shows a reconstruction of the southwestern North Island paleogeography for the base of the Mangapanian Stage (2.8 Ma). The paleoshoreline drawn here is derived from seismic data (Uruski, 1998) for subsurface geology beneath the marine part of the basin and the eroded limit for the onland part of the basin. The reconstruction is based on the maximum flooding at the peak of the interglacial immediately following deposition of the Mangapani Shell Conglomerate. The current outcrop represents part of the northern limb of the basin, and there must have been a paleoshoreline somewhere to the north. The western boundary of the basin at this time appears to have been mainly closed to the Tasman Sea, with Mangapanian sediments onlapping the Patea–Tongaporutu High in the north, and feathering out in basin margins to the west and south. This observation is supported by patterns of both low faunal diversity in foraminiferal census and low planktic foraminiferal content in the Waipipian–Mangapanian Mangaweka Mudstone (Collen, 1972; Kamp *et al.,* 1998), both of which indicate enclosure and isolation of the basin around this time. This reconstruction follows that of Thompson *et al.,* (1994) and Beu (1995) in having the Wanganui and East coast basins connected across the current position of the Ruahine Ranges. This is supported by the deepest-water expression of the Wp / Wm boundary being in the eastern part of the basin. In agreement with Beu (1995), a shallow sill or area of non-deposition in the vicinity of the Manawatu Gorge is inferred, based on the absence of Mangapanian strata in the Saddle road section where Waipipian strata are unconformably overlain by Nukumaruan gravels (Beanland, 1995; Lille, 1953). The source of sediment to the basin was probably bi-directional, as older sediment eroded from Cenozoic rocks uplifted to the north of the basin were reworked southwards, and northwards-flowing rivers on the Marlborough Shield transported sediment north from the South Island.

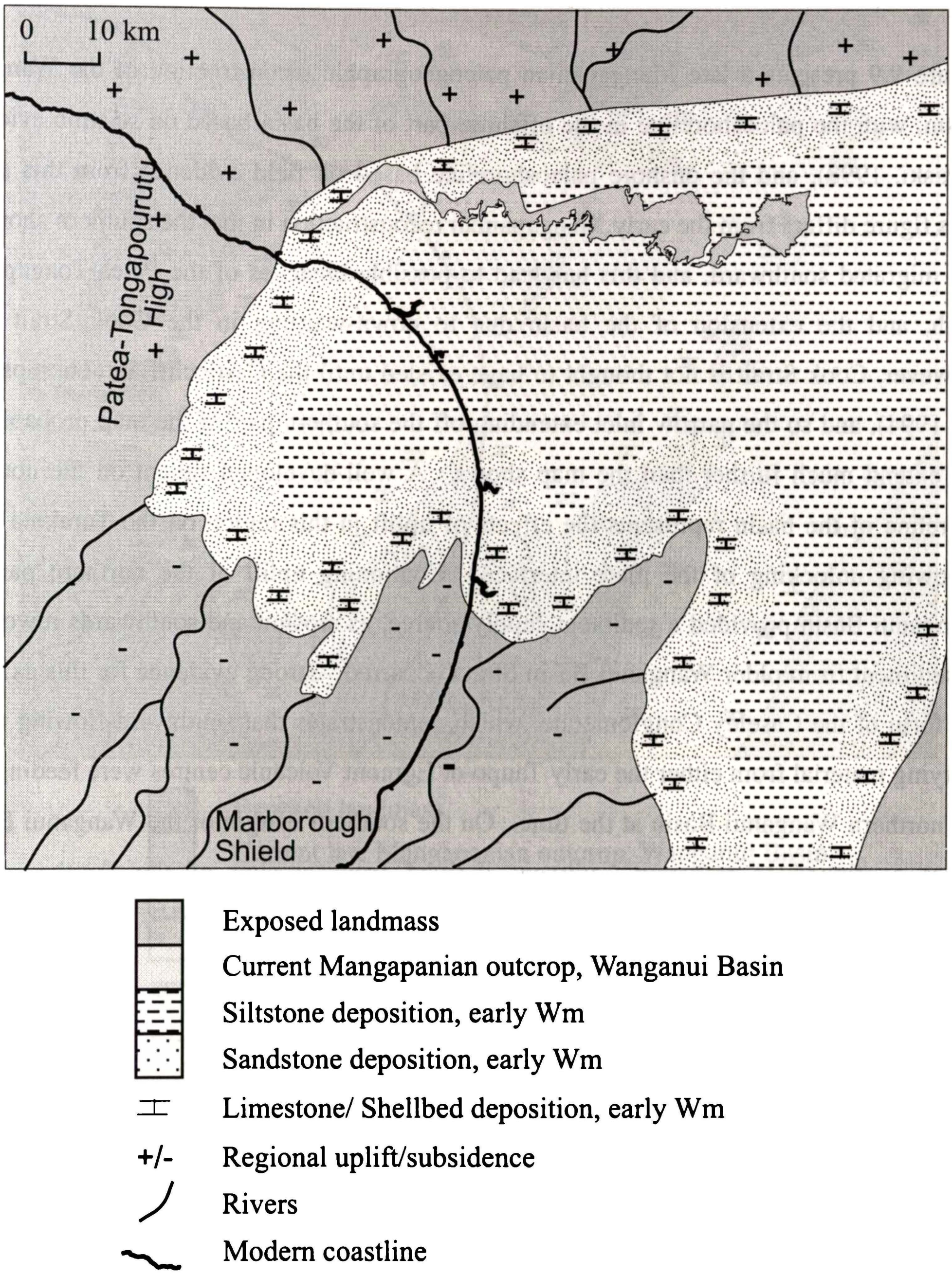


Figure 9.8: Paleogeographic reconstruction, early Mangapanian maximum flooding. Reconstruction is based on shoreline at time of deposition of upper part of Mangapani Shell Conglomerate. East coast paleogeography from Thompson *et al.* (1994) and Beu (1995).

Late Mangapanian:

Figure 9.9 presents a late Mangapanian paleogeographic reconstruction of the Wanganui Basin, with the paleoshoreline in the offshore part of the basin based on seismic evidence (Uruski, 1998), and the onshore paleoshoreline based on field evidence from this study. This figure differs from the early Mangapanian reconstruction in that the southern shoreline has migrated southward, and this has lead to possible breaches of the Patea-Tongaporutu High, and the extension of the basin due to down-warping in the Cook Strait area. However, Cook Strait is not thought to have existed until the Castlecliffian (Thompson *et al.,* 1994), and so the narrow inlet extending off the southern part of the map probably did not extend much further than the map shows. A well-developed salient on the northern shoreline of the basin represents the effects of uplift in this region on the Turakina High following unlocking of the plate interface. Continuing uplift of the northern parts of Wanganui Basin provided a sediment supply source, as erosion and southwards reworking of sediment from older Wanganui Basin Strata occurred. Strong evidence for this exists in the form of the Caseley Conglomerate, which demonstrates that southward-flowing rivers carrying material from either the early Taupo or Egmont Volcanic centres were feeding into the northern Wanganui Basin at the time. On the southern margin of the Wanganui Basin, rivers continued to transport sediment derived from erosion of the Southern Alps northwards on the subsiding Marlborough Shield.

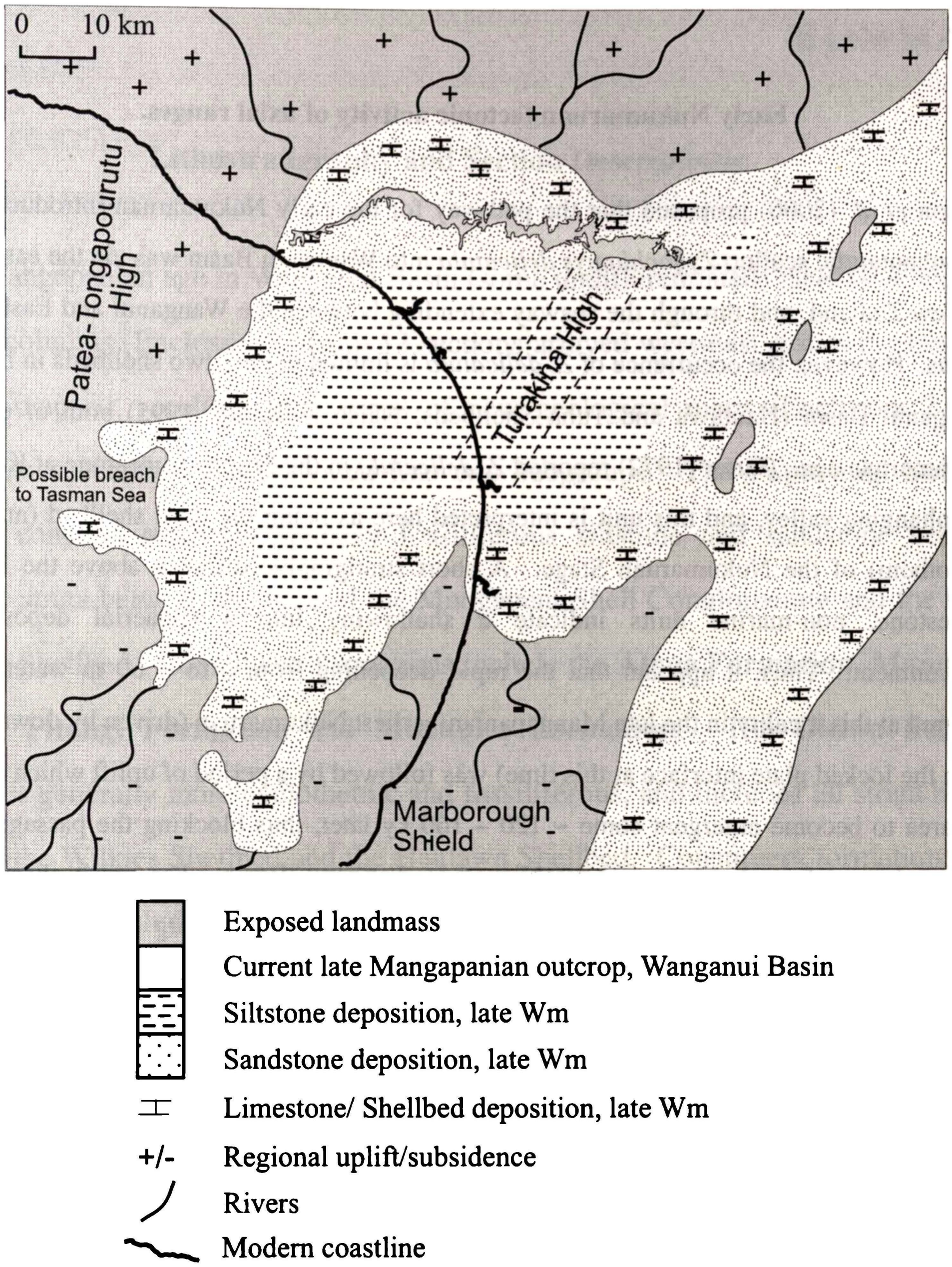


Figure 9.9: Paleogeographic reconstruction, late Mangapanian maximum flooding. Reconstruction is based on shoreline at time of deposition of upper part of School Shellbed. East coast paleogeography from Thompson *et al.* (1994) and Beu (1995).

Early Nukumaruan tectonic activity of axial ranges.

Nelson *et al.* (2000) proposed that the pathway for the early Nukumaruan introduction of the subantarctic scallop *Zygochlamys delicatula* into Wanganui Basin was via the east coast of New Zealand, and through the seaway extending between the Wanganui and East Coast basins. However, the occurrence of *Z. delicatula* is limited to only two shellbeds in most of Wanganui Basin (Hautawa and Tuha Shellbeds; Naish & Kamp, 1995) both of earliest Nukumaruan age. Carter (1972) reported *Z. delicatula* in the Piripiri Limestone at Komako in Pohangina valley, and this unit is interpreted here as being the third shellbed (and thus cyclothem) of the Nukumaruan Stage. A short stratigraphic distance above the Piripiri Limestone, non-marine units indicate a shallowing into a subaerial depositional environment. Thus, it appears that the rapid deepening from 0 to ~ 60 m water depth inferred at this locality in the late Mangapanian-earliest Nukumaruan (driven by down-warp form the locked plate interface at this time) was followed by a period of uplift which caused the area to become emergent some ~ 120 – 160 ky later, thus blocking the passage of *Z. delicatula* spat from becoming re-established in Wanganui Basin. The uplift observed at this locality was almost certainly the result of compressional loading of the lithosphere following the re-establishment of the locked plate interface in the early Nukumaruan. While the initial effect of the locked plate interface was to subside this region, lateral stresses transmitted from the accretionary wedge complex in the East Coast area forced uplift of this region to occur, and created a new eastern margin for the Wanganui Basin. This hypothesis is consistent with the occurrence of Nukumaruan gravels in the Saddle Road section near Manawatu Gorge (Beanland, 1995), which are possibly linked to the uplift recorded in the Komako stratigraphy, but represent a more advanced stage of uplift as the basement-cored antiforms penetrated through the Cenozoic rock succession. Therefore, *Z. delicatula* was able to enter Wanganui Basin from the east coast during OIS 88 to 84, but its access was closed off again after OIS 84 by compressional uplift at the present site of the Ruahine Range.

CHAPTER TEN:

SUMMARY.

Lithostratigraphy and Section Descriptions.

Strata of Mangapanian age in Wanganui Basin (some undifferentiated) have been logged as a series of columns (Enclosure 1) from 13 sections arrayed west-east across the basin, and have been mapped, resulting in a series of new geological maps (Enclosure 2). The Mangapanian succession is subdivided into two subgroups. The **Paparangi Subgroup** (emended) contains generally sparsely fossiliferous siltstone and sandstone beds, and includes all strata between the base of the Mangapani Shell Conglomerate and the base of the Wilkies Shellbed. Constituent formations include the **Atene Formation, Mangaweka Mudstone, Pitangi Formation** and **Moukuku Formation.** The **Okiwa Subgroup** (emended) is generally more cyclothemic and fossiliferous, and includes all strata between the base of the Wilkies Shellbed and the Hautawa Shellbed. Constituent formations of the Okiwa Subgroup include the **Whauteihi Formation, Whakaihuwaka Formation** and **Parikino Formation.**

Formational boundaries are mainly located at the base of shellbeds, as this type of contact is the most mappable within the succession. Individual sandstone, siltstone and shellbed units within formations are assigned member status.

Chronology.

Sequences within the Mangapanian succession provide the framework for the integrated chronology, as they subdivide the strata into surfaces of regional extent, and shellbeds at the base of these sequences contain fossil molluscs. New fossil collections made during this study allow refinement and minor emendations to the New Zealand Geological Timescale for molluscan bioevents occurring at the Wp-Wm and Wm-Wn Stage boundaries. One significant discovery is that the FO of dextrally coiled *Globorotalia crassaformis* does not mark the Wp-Wm Stage boundary, but lies well below it. Comparison between molluscan and formainiferal bioevents is demonstrated in the Wanganui River section. Two rhyolitic tephra (**Eagle Hill** and **Otere** (new)) have been numerically dated. These tephras have U-Pb SHRIMP ages of 2.85 ± 0.20 Ma and 2.71 ± 0.25 Ma, repectively. A single crystal (U-Th)/He age of the Otere Tephra gives an age of 2.57 ± 0.04. These ages constrain new and revised magnetostratigraphic data for the Rangitikei River, Turakina River, Whangaehu River, Wanganui River, and Kauarapaoa and Paparangi sections. This allows assignment of the Gauss / Matayama transition to a normal to reverse boundary located c. 260-290 m below the Hautawa Shellbed in the Rangitikei, Turakina and Wanganui River sections. A small normal chron occurring between the Tirotiro and Te Rama Shellbeds is correlated with the "X" event cryptochron (2.44 - 2.42 Ma, in OIS 95), and occurs 100-125 m below the Hautawa Shellbed in the Paparangi, Kauarapaoa, Whangaehu River and Turakina River sections.

Ages for paleomagnetic transitions and numerical ages of tephra together with biostratigraphy has allowed the sequences within the Mangapanian Stage to be correlated with ^{18}O Stages G10-88 (2.79 Ma – 2.28 Ma). This provides a numerical age range to be applied to each sequence within the succession.

The Mangapani Shell Conglomerate.

The Mangapani Shellbed crops out between Waitotara township (near State Highway 3) and several sections eastward to Atene, in the Wanganui River valley. Several molluscan bioevents (mainly first occurences) are associated with the shellbed, which assist with correlation of the shellbed across this part of the basin. The correlation of the Mangapani Shell Conglomerate from the Waitotara River valley to the Wanganui River valley allows the unit to be positioned within an established magnetostratigraphy for the first time. An integrated chronology of tephra, paleomagentic and Oxygen Isotope Stage matching indicates that the Mangapani Shell Conglomerate lies within Oxygen Isotope Stage G10 - G11, at 2.81 - 2.79 Ma.

Descriptive logs of the unit combined with facies descriptions and molluscan depositional depth analysis reveal that the shellbed accumulated in a mainly inner-shelf setting, on a westward shoaling shelf. Fossil molluscs within the shellbed indicate that the Mangapani Shell Conglomerate accumulated during a transgression onto this shelf. The magnitude of this sea-level rise was about 30 - 50 m, which is consistent with a glacio-eustatic origin.

The Mangapani Shell Conglomerate, Soulsby Siltstone and Atene Sandstone comprise a cyclothemic sequence. The Mangapani Shell Conglomerate is a transgressive systems tract (TST), made up of an onlap and a backlap shellbed, which are separated by a shore-connected sediment wedge (SCW) in the Waitotara River valley section. The Soulsby Siltstone and Atene Sandstone are positioned within the HST and RST. The correlation of this sequence with oxygen isotope stages G10 - G6 provides independent information on sea-level changes during accumulation of the sequence, and the one-dimensional depositional model of cyclothem development of Naish & Kamp (1997) can be applied to the sequence.

The Wilkies Shellbed.

The Wilkies Shellbed is a unique unit within the Wanganui Basin Plio-Pleistocene succession, as it contains a great thickness (up to 15 m in places) of the extinct giant oyster *Crassostrea ingens.* The shellbed occurs within the middle of the Mangapanian Stage, and in this study is correlated with oxygen isotope stages 100 - 101, giving it a numerical age of 2.48 - 2.50 Ma. While the Wilkies Shellbed is easily correlated between sections in the central parts of the basin from Okiwa Trig to Parihauhau Road, correlation of the shellbed into sections west of Okiwa Trig is uncertain, necessitating the establishment of a new type section at Te Rimu in the Wanganui River valley. Descriptions, section logs, facies analysis and molluscan depth analysis of the Wilkies Shellbed, Cable Siltstone and Te Rimu Sandstone confirm that this succession comprises a cyclothemic sequence, which accumulated on a westward-shallowing paleoshelf. In the western parts of the basin, this sequence is truncated by an unconformity, and it may not exist west of Okiwa Trig.

The Wilkies Shellbed itself accumulated as an oyster biostrome resulting from stratigraphic condensation during a transgression. Little evidence for the Wilkies Shellbed having formed in an estuarine setting exists, and thus the habitats of modern *Crassostrea* species are not suitable proxies for *C. ingens.* The Wilkies Shellbed has two distinctive parts: The lower part contains mainly reworked and disarticulated bivalves, and is classified here as an onlap shellbed. The upper part is dominated by *in situ C. ingens*, and is classified as a backlap shellbed. The onlap shellbed only occurs west of Kauarapaoa valley. The backlap shellbed occurs between the Whangaehu valley and Okiwa Trig. Above the Wilkies Shellbed, the Cable Silstone and Te Rimu Sandstone are placed within the highstand and regressive systems tracts.

The Hautawa Shellbed.

The Hautawa Shellbed is one of the most important stratigraphic horizons within Wanganui Basin, as it contains multiple bioevents that define the Mangapanian - Nukumaruan Stage Boundary. Notably, the FO of the subantarctic scallop *Zygochlamys delicatula* occurs within the Hautawa Shellbed, and indicates the incursion of a colder water mass into the region during the late Pliocene. New and re-interpreted paleomagnetic data from several sections indicate a correlation between the Hautawa Shellbed and oxygen isotope stages 88 - 89, giving it an age of 2.26 - 2.28 Ma. This is comparable with the assignment of the Mangapanian - Nukumaruan Stage Boundary in the Mangaopari Stream section in south–eastern North Island (Orpin *et al.*, 1998) with Stages 86 - 87. The Kuranui Limestone is a direct correlative of the Hautawa Shellbed, as is the "Basal Conglomerate" of Carter (1972) in the Pohangina valley. Descriptions, section logs, facies analysis and molluscan depth analysis of the Hautawa Shellbed, Tuha Siltstone and Upokonui Sandstone confirm that this succession comprises a cyclothemic sequence, which contains a record of relative sea-level rise and fall. Molluscan depth analysis reveals that the Hautawa Shellbed accumulated during a transgression, which is estimated as having a magnitude of 50 - 60 m, with the subsequent regression driving progressively shallowing terrigenous sediment deposition (Tuha Siltstone and Upokonui Sandstone). Sequence stratigraphic interpretation of this sequence shows that the Hautawa Shellbed is a TST, comprised of onlap and backlap shellbeds. The onlap shellbed occurs only west of the Whangaehu River valley, and comprises the entire TST in and to the west of Wairangi. The backlap shellbed occurs only east of the Kauarapaoa valley, and comprises the entire shellbed in the West Road, Watershed Road and Rangitikei River sections. Above the Hautawa Shellbed, the Tuha Siltstone and Upokonui Sandstone are assigned to the HST and RST.

A Sequence Stratigraphic Model for 41 k.y. Sequences.

The sequence "motifs" of Saul *et al.* (1999) do not adequately account for the various sequence architectures observed in this study. Detailed investigation of sequences including the Mangapani Shell Conglomerate, Wilkies Shellbed and Hautawa Shellbed reveal a similarity between the depositional systems. Common features in each of these three sequences provide constraints upon which a model cyclothem is based.

The model cyclothem is two-dimensional, and is intended to illustrate the distribution of facies and sequence stratigraphic surfaces across a conceptual paleoshelf. One important outcome resulting from construction of the model cyclothem is the recognition that the HST - RST boundary does not nessecarily follow the siltstone - sandstone facies boundary, and cuts across it in most sequences.

Comparison of other sequences within the Mangapanian succession with the model cyclothem reveals subtle patterns of sequence architecture, from which a prediction of paleoshelf position can be made. While most sequences exhibit a consistent westward-shallowing trend, many sequences appear to exhibit their shallowest expression in the central parts of the basin, with increases in water depth both eastward and westward of this point. The point of inferred closest proximity to a paleoshoreline in outcrop is designated Point "S". Tracing the location of Point "S" for successive sequences reveals that it occurs in the central part of the basin during late Mangapanian time. A time-space view of Mangapanian strata shows a link between unconformable sequence boundaries, shoreface deposits, onlap shellbeds and a proximity to Point "S".

Geological History and Basin Synthesis.

Seismic reflection profiles reveal several features about the subcrop geology of Wanganui Basin that assist with interpretation of the geological history of the basin for Mangapanian time. The Patea-Tongaporutu High occurs in the western part of the basin, and is interpreted as a fore-bulge, resulting from lithospheric flexure driven by tectonic subsidence above a subducting locked plate interface. Mangapanian strata thin towards and onlap the Patea-Tongaporutu High, indicating that it formed a basin margin for at least part of this period. To the east, reverse-fault-bounded compressional antiforms occur, which are possibly the result of compressional stress transmitted into Wanganui Basin from the Hikurangi margin accretionary complex.

The position of Point "S" is considered to be related to changes in the dynamics of the basin through time. The movement of Point "S" to the central part of the basin during late Mangapanian time is correlated with slip on the Australia / Pacific Plate interface. This had the effect of lessening the rate of tectonic subsidence, and resulted in minor basin inversion, with the greatest upward movement occurring in the vicinity of the Turakina High. Subsequent relocking of the plate interface results in the resumption of tectonic subsidence. At the start of Mangapanian time (2.79 Ma, OIS G10), the plate interface was locked, and it remained so for 240 k.y., until 2.55 Ma (OIS 102). An interval of unlocking and slip on the plate interface continued for approximately 20 k.y., until relocking occured at 2.53 Ma (OIS 101). Subsidence then continued for 70 k.y., until 2.46 Ma (OIS 97). Between 2.46 Ma and 2.28Ma (OIS 88), the plate interface was unlocked and slipping, during an interval of 180 k.y.

Paleogeographic maps depicting the shape of Wanganui Basin at both the beginning and end of Mangapanian time demonstrate southwards displacement of the basin depocentre, and show that a western basin margin probably separated the Wanganui Basin from the Tasman Sea.

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APPENDIX ONE:

TEXTURAL DATA.

Textural samples were collected from most sections, at approximately 2 m stratigraphic intervals. Sample spilts were dried and both Hydrogen Perioxide and Calgon were added until disaggregation was complete. Samples were analysed with the University of Waikato Malvern laser mastersizer, and the sand / silt ratio recorded. The samples have been assigned University of Waikato sample numbers and are lodged in the Earth Sciences rock store. Typically, about 0.2 – 0.5 kg of sample was collected, and about 1 – 5 grams used for the particle sizing measurements. The sampling localities are plotted on the geological maps (Enclosure 2), with the endpoints of the sampling transects linked to these tables by the last three digits of the University of Waikato sample number.

Textural Sample Details for Mangapanian strata, Okiwa and Kuranui sections				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22 .
OK75	97647	0	87.76	713161
OK76	97648	2	78.24	
OK77	97649	4	53.94	
OK78	97650	6	44.06	
OK79	97651	8	37.56	
OK80	97652	10	45.94	713160
OK87	97653	12	34.45	713160
OK88	97654	14	20.93	
OK89	97655	16	11.27	
OK90	97656	18	12.05	
OK91	97657	20	11.36	
OK92	97658	23	13.82	
OK93	97659	25	17.12	
OK94	97660	27	38.08	
OK95	97661	29	47.04	
OK96	97662	31	61.54	
OK97	97663	33	76.58	
OK98	97664	35	67.28	
OK99	97665	37	64.52	
OK100	97666	39	31.26	713159
OK123	97667	41	31.28	714159
OK124	97668	43	26.99	
OK125	97669	45	15.04	
OK126	97670	47	41.33	
OK127	97671	49	39.15	
OK128	97672	51	13.18	
OK129	97673	53	10.52	
OK130	97674	55	2.13	
OK131	97675	57	16.16	
OK132	97676	59	32.65	
OK133	97677	61	18.75	
OK134	97678	63	21.59	
OK135	97679	65	22.93	
OK136	97680	67	23.44	
OK137	97681	69	22.94	
OK138	97682	71	34.49	
OK139	97683	73	39.07	
OK140	97684	75	76.64	714158

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
OK200	97685	83	8.17	714598
OK201	97686	85	6.69	
OK202	97687	87	10.98	
OK203	97688	89	10.85	
OK204	97689	93	10.8	
OK205	97690	95	14.71	
OK206	97691	97	13.75	
OK207	97692	99	25.52	
OK208	97693	101	16.52	
OK209	97694	103	29.39	
OK210	97695	105	29.19	
OK211	97696	107	21.62	714597
OK300	97697	109	4.6	714597
OK301	97698	111	9.28	
OK302	97699	113	3.44	
OK303	97700	115	7.46	
OK305	97702	117	8.91	
OK306	97703	119	13.69	
OK307	97704	121	9.7	
OK308	97705	123	6.24	
OK309	97706	125	7.02	
OK310	97707	127	18.79	
OK311	97708	129	11.07	
OK312	97709	131	5.2	
OK313	97710	133	12.85	
OK314	97711	135	7.85	714597
OK700	97712	137	41.68	718597
OK701	97713	139	14.46	718597
OK840	971073	161	73.08	
OK841	97714	163	46.45	718597
OK842	97715	165	24.13	
OK843	97716	167	26.44	
OK844	97717	169	46.55	
OK845	97718	171	58.14	
OK846	97719	173	42.66	
OK847	97720	175	61.56	
OK848	97721	177	27.28	
OK849	97722	179	32.14	
OK850	97723	181	41.09	717597
LQ1	97731	165.5		688566
LQ2	97732	167.5		
LQ3	97733	169.5		
LQ4	97734	173.5		
LQ5	97735	175.5		
LQ6	97736	177.5		
LQ7	97737	180.5		
LQ10	97738	182.5		688567
LQ44	97724	200	81.05	689568
LQ45	97725	203	95.93	
LQ46	97726	205	94.15	
LQ47	97727	207	94.8	
LQ48	97728	209	95.03	
LQ49	97729	211	84.1	
LQ50	97730	213	36.1	690569

Textural Sample Details for Mangapanian strata, Rangitatau East road, at Paparangi				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
RE100	97580	0	40.5	784643
RE101	97581	2	25.79	
RE102	97582	4	49.24	
RE103	97583	6	11.61	
RE104	97584	7	16.86	
RE105	97585	8	13.76	
RE106	97586	11	13.97	
RE107	97587	13	10.61	
RE108	97588	15	26.64	
RE109	97589	17	84.79	
RE110	97590	19	79.15	
RE111	97591	21	82.64	
RE200	97592	33.5	79.24	
RE201	97593	38	8.07	
RE202	97594	39.5	23.05	785640
RE210	97595	44	59.98	784638
RE211	97596	46	50.17	
RE212	97597	48	20.47	
RE213	97598	50	5.81	
RE214	97599	52	5.46	
RE215	97600	54	4.91	
RE216	97601	56	7.98	
RE217	97602	58	5.46	
RE218	97603	60	11.75	
RE219	97604	62	11.48	
RE220	97605	64	9.08	
RE221	97606	66	12.72	
RE222	97607	68	1.48	
RE223	97608	70	1.93	
RE224	97609	72	1.84	
RE225	97610	74	5.8	
RE226	97611	76	7.05	
RE227	97612	78	9.83	
RE228	97613	80	32.97	
RE229	97614	81	12.72	
RE230	97615	82	2.85	
RE231	97616	83	2.93	
RE232	97617	84	3.37	
RE234	97619	86	33.03	
RE235	97620	88	26.75	
RE236	97621	90	35.9	
RE240	97622	92	2.62	
RE241	97623	94	3.89	
RE242	97624	96	6.41	
RE243	97625	98	6.5	
RE244	97626	100	3.63	
RE245	97627	101	5.04	
RE246	97628	103	7.61	
RE247	97629	105	8.4	775636

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
RE300	97630	107	26.2	774634
RE301	97631	109	30.15	
RE302	97632	114.5	44.33	
RE302a	97633	115.8	23.01	
RE302b	97634	117	9.49	
RE303	97635	125	15.55	
RE304	97636	128	24.45	
RE305	97637	130	21.69	
RE306	97638	132	30.48	
RE307	97639	134	. 17.04	
RE308	97640	138	45.54	
RE309	97641	142	61.35	
RE310	97642	144	83.5	
RE311	97644	146	87.46	
RE312	97645	148	93.49	
RE313	97646	150	86.69	
RE400	97647	153	19.07	773632
RE476	971048	154	12.6	768632
RE477	971049	156	10.13	
RE478	971050	158	7.11	
RE479	971051	160	6.26	
RE480	971052	162	16.37	
RE481	971053	164	40.48	
RE482	971054	166	33.26	
RE483	971055	168	23.16	
RE484	971056	170	29.33	
RE485	971057	172	33.83	
RE486	971058	174	32.44	
RE487	971059	176	44.41	
RE488	971060	178	44.51	
RE489	971061	180	12.49	
RE490	971062	182	21.51	
RE491	971063	184	53.02	
RE492	971064	186	78.83	
RE493	971065	188	93.09	
RE494	971066	190	93.06	
RE495	971067	192	94.54	
RE496	971068	194	88.98	
RE497	971069	196	93.31	
RE498	971070	198	79.79	
RE499	971071	200	89.42	
RE500	971072	202	91.68	763628

Textural Sample Details for Mangapanian strata, Wairangi Station				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
SS1	97464	2	31.21	846626
SS2	97465	4	21	
SS3		25	10.69	
SS100	97466	35	10.83	
SS101	97467	37	41.74	
SS102	97468	39	45.84	
SS103	97469	41	81.29	
SS104	97470	43	76.15	
SS105	97471	45	51.58	
SS106	97472	47	52.06	
SS107	97473	49	52.11	
SS108	97474	51	33.42	
SS109	97475	53	32.86	
SS110	97476	55	63.29	
SS111	97477	57	38.02	
SS112	97478	59	21.62	
SS113	97479	64	82.43	
SS114	97480	65	23.69	
SS115	97481	67	32.77	
SS116	97482	69	22.47	
SS117	97483	71	27.68	
SS118	97484	71.5	93.81	
SS119	97485	72	49.14	
SS120	97486	74	32.22	
SS121	97487	76	20.53	
SS122	97488	78	26.14	
SS123	97489	80	26.37	
SS124	97490	82	38.26	
SS125	97491	84	24.81	
SS126	97492	86	30.55	
SS127	97493	89	39.99	
SS128	97494	91	42.46	
SS129	97495	93	33.97	
SS130	97496	95	30.01	
SS131	97497	104	36.82	
SS200	97498	124	42.9	
SS201	97499	126	53.94	
SS202	97500	128	58.23	
SS203	97501	130	60.4	
SS204	97502	132	46.42	
SS205	97503	134	41.7	
SS206	97504	136	59.15	
SS207	97505	138	53.24	
SS208	97506	140	57.45	
SS209	97507	142	35.82	
SS210	97508	144	42.22	
SS211	97509	146	24.92	
SS212	97510	148	30.94	
SS213	97511	151	72.94	
SS214	97512	153	73.11	
SS215	97513	156	66.19	
SS216	97514	158	77.05	
SS217	97515	160	71.06	
SS218	97516	162	86.67	
SS219	97517	164	49.24	

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
SS219a	97518	166	32.99	
SS219b	97519	168	22.14	
SS220	97520	170	24.19	
SS221	97521	172	22.21	
SS222	97522	176	8.19	
SS223	97523	178	16.67	
SS224	97524	180	17.19	
SS225	97525	182	10.55	
SS226	97526	184	26.34	
SS227	97527	186	11.4	
SS228	97528	188	24.46	
SS229	97529	190	64.22	
SS230	97530	192	90.93	
SS231	97531	194	85.37	
SS232	97532	196	77.81	
SS233	97533	198	65.81	
SS234	97534	200	79.74	
SS235	97535	202	71.96	
SS236	97536	205	69.28	
SS237	97537	207	53.11	
SS238	97538	209	55.75	
SS239	97539	211	70.42	
SS240	97540	213	58.92	
SS241	97541	215	65.62	
SS242	97542	217	51.42	
SS243	97543	219	94.71	
SS337	97544	221	10.75	
SS338	97545	223	8.51	
SS339	97546	225	11.79	
SS340	97547	227	6.51	
SS341	97548	229	12.02	
SS342	97549	231	7.56	
SS343	97550	233	11.75	
SS344	97551	235	7.35	
SS345	97552	237	15.13	
SS346	97553	239	27.87	
SS347	97554	241	33.28	
SS348	97555	243	80.62	
SS349	97556	245	84.75	
SS350	97557	247	34.87	841616
SS600	97558	412.5	89.4	831616
SS601	97559	416	43.4	
SS602	97560	419.5	63.98	
SS603	97561	423	92.43	
SS604	97562	426.5	18.42	
SS605	97563	430	28.5	
SS606	97564	433.5	12.36	
SS607	97565	437	38.81	
SS608	97566	440.5	65.86	
SS609	97567	444	56.57	
SS610	97568	447.5	80.49	
SS611	97569	451	87.73	
SS612	97570	454.5	45.1	
SS613	97571	458	12.08	
SS614	97572	461.5	37.43	
SS615	97573	466.5	21.44	
SS616	97574	470	6.87	
SS617	97575	473.5	16.09	
SS618	97576	477	7.53	
SS620	97577	480.5	14.89	
SS621	97578	484	15.65	
SS622	97579	487.5	84.35	833613

Textural Sample Details for Mangapanian strata, Kauarapaoa valley				
Field code #	Uni. of Waikato. Sample #	Stratigraphic Height (m)	Sand (vol%)	Grid ref. NZMS S22
HC1	97301	0	13.8	901593
HC2	97302	4	15.94	
HC3	97303	6	13.22	
HC4	97304	8		
HC5	97305	10	63.15	
HC6	97306	12		
HC7	97307	13	48.51	
HC8	97308	15.2		
HC9	97309	16.2	64.73	
HC10	97310	18.2	68.74	
HC11	97311	20.2	83.15	
HC12	97312	21.2	75.56	
HC13	97313	22.2	75.95	
HC14	97314	24.2	81.36	
HC15	97315	26.2		
HC16	97316	28	56.21	903594
HC100	97317	46.5	96.45	904598
HC101	97318	50.5	96.58	
HC102	97319	52.5	93.97	
HC103	97320	54.5	94.96	
HC104	97321	56.5	94.25	
HC105	97322	58.5	92.54	
HC106	97323	60.5	90.04	
HC107	97324	62.5	87.15	
HC108	97325	64.5	86.81	
HC109	97326	66.5	86.66	
HC110	97327	68.5	92.26	
HC111	97328	70.5	85.49	
HC112	97329	72.5	78.66	
HC113	97330	74.5	90.07	
HC114	97331	76.5	81.91	
HC115	97332	78.5	28.11	
HC116	97333	80.5	26.73	
HC117	97334	83	25.07	
HC118	97335	85	57.4	
HC119	97336			
HC120	97337	87.5	94.45	
HC121	97338		97.96	
HC122	97339	89.5	94.54	
HC123	97340	91.5	95.77	
HC124	97341	93.5	91.76	
HC125	97342	95.5	62.24	
HC126	97343	97.5	63.76	
HC127	97344	100	73.71	
HC128	97345	102	78.36	
HC129	97346	104	73.25	
HC130	97347	106	39.95	
HC131	97348	108	12.93	
HC132	97349	110	26.04	
HC200	97350	113.1	84.08	
HC201	97351	114.6	79.57	
HC202	97352	114.9	76.72	
HC203	97353	116.9	78.53	
HC204	97354	118.9	78.2	
HC205	97355	120.9	68.03	
HC206	97356	122.9	67.94	
HC207	97357	124.9	44.6	
HC208	97358	127.9	83.91	
HC209	97359	129.9		
HC210	97360	131.9	96.29	
HC211	97361	133.9	95.83	
HC212	97362	135.9	94.12	
HC213	97363	137.9	91.24	
HC214	97364	139.9	91.9	

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
HC215	97365	141.9	91.71	
HC216	97366	143.9	96.84	
HC217	97367	144.4	93.79	
HC218	97368	146.4	92.01	
HC219	97369	148.4	92.63	
HC220	97370	150.4	94.91	
HC221	97371	152.4	91.92	
HC222	97372	154.4	92.56	
HC223	97373	156.4	92.24	
HC224	97374	158.4	87.52	
HC225	97375	160.4	90	
HC226	97376	162.4	76.01	
HC227	97377		75.06	914597
JB100	97378		63.99	905564
JB101	97379		56.72	
JB102	97380		96.58	
JB103	97381	130	95.89	
JB104	97382	132	95.7	
JB105	97383	134	93.55	
JB106	97384	136	95.2	
JB107	97385	138	95.48	
JB108	97386	140	93.51	
JB109	97387	142	93.12	
JB110	97388	144	93	
JB111	97389	146	94.75	
JB112	97390	148	89.39	
JB113	97391	150	91.17	
JB114	97392	152	85.06	
JB115	97393	156	76.08	
JB116	97394	160	51.33	
JB117	97395	162.5	79.4	
JB118	97396	164	71.68	
JB119	97397	170	9.37	
JB120	97398	172	13.17	
JB320	97407	178.6	96.43	
JB321	97408	179.6	77.2	
JB322	97409	181.6	72.45	
JB323	97410	183.6	61.35	
JB324	97411	185.6	88.23	
JB325	97412	187.6	80.15	
JB326	97413	189.6	82.32	
JB327	97414	191.6	37.95	
JB328	97415	193.6	85.38	
JB329	97416	195.6	57.8	
JB330	97417	197.6	55.38	
JB331	97418	199.6	74.36	
JB332	97419	201.6	73.38	
JB333	97420	203.6	72.34	
JB334	97421	205.6	50.31	
JB335	97422	207.6	52.63	
JB336	97423	209.6	60.45	
JB337	97424	211.6	82.98	
JB439	97425	21.36	30.24	
JB440	97426	215.6	85.53	
JB441	97427	217.6	85.08	
JB442	97428	219.6	15.93	
JB443	97429	221.6	81.17	
JB444	97430	223.6	55.87	
JB445	97431	225.6	54.13	
JB446	97432	227.6	63.44	
JB447	97433	231.6	25.89	
JB448	97434	233.6	51.05	
JB449	97435	235.6	38.44	
JB450	97436	232.1	34.62	

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
JB500	97437	234.4	96.31	
JB501	97438	236.4	97.67	
JB502	97439	238.4	92.76	
JB503	97440	240.4	90.63	
JB504	97441	242.4	95.46	
JB505	97442	244.4	82.59	907564
JB732	97443	250.4	11.85	901554
JB733	97444	254.4	8.08	
JB734	97445	256.4	12.08	
JB735	97446	258.4	6.94	
JB736	97447	260.4	7.23	
JB737	97448	262.4	5.8	
JB738	97449	264.4	6.76	
JB739	97450	266.4	4.29	
JB740	97451	268.4	5.73	
JB741	97452	270.4	6.42	
JB742	97453	272.4	5.12	
JB743	97454	274.4	6.23	
JB744	97455	276.4	10.7	
JB745	97456	278.4	5.64	
JB746	97457	280.4	34.1	
JB747	97458	282.4	10.25	
JB748	97459	284.4	8.75	
JB749	97460	286.4	15.41	
JB750	97461	288.4	13.09	
JB809	97462	247.9		
JB810	97463	246.4		904555
KRS1	399	31.5	7.16	900580
KRS2	400	34.5	9.45	
KRS3	401	38.5	7.95	900580
KRS146	402			903573
KRS147	403			
KRS148	404			
KRS149	405			
KRS150	406			903573

Textural Sample Details for Waipipian and Mangapanian strata, Wanganui River Section				
(H*** series samples from Hayton, 1998)				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS
H592	W962490	0	26.41	S21 934649
H593	W962491	5	20.04	S21 933648
H498	W962492	10	13.54	S21 933649
H488	W962493	16	52	S21 932648
H480	W962496	20	7.6	S21 932648
H487	W962497	27	7.84	S21 932648
H481	W962498	35	8.27	S21 932648
H482	W962499	40	10.01	S21 932648
H483	W962500	45	7.77	S21 932648
H484	W962501	51	3.5	S21 932648
H485	W962502	55	5.96	S21 932648
H486	W962503	60	6.13	S21 932648
H521	W962504	88	22.61	S21 938639
H598	W962505	102	42.55	S21 923633
H597	W962506	108	65.39	S21 923632
H596	W962507	113	38.37	S21 923632
H595	W962508	113	70.96	S21 923632
H594	W962510	115	12.16	S21 923632
H502	W962511	117	13.43	S21 923632
H503	W962512	122	21.15	S21 923632
H599	W962513	133	15.85	S21 923633
H519	W962514	140	19.06	S21 931631
H518	W962515	143	8.03	S21 931631
H520	W962516	147	6.57	S21 931631
H539	W962517	153	7.07	S21 926630
H515	W962518	153	6.34	S21 931631
H538	W962519	154	13.35	S21 926630
H537	W962520	155	13.96	S21 926630
H516	W962521	157	19.87	S21 931631
H517	W962522	160	46.97	S21 931631
H504	W962523	185	73.21	S21 929622
H505	W962524	190	18.01	S21 929622
H506	W962525	192	64.32	S21 929622
H513	W962526	200	65.33	S21 934628
H600	W962527	205	61.07	S21 937623
H514	W962528	210	29.39	S21 933628
H601	W962529	211.5	71.81	S21 937623
H602	W962530	214	40.7	S21 937623
H603	W962531	216.5	81.38	S21 937623
H604	W962532	221	26.91	S21 937623
H510	W962533	225	17.73	S21 937624
H511	W962534	227	11.47	S21 937624
H512	W962535	230	8.07	S21 937624
H507	W962536	235	4.84	S21 936620
H508	W962537	242	4.2	S21 936620
H509	W962538	248	3.93	S21 936620
H643	W962539	255	2.61	S21 931630
H644	W962540	260	2.44	S21 931630
H645	W962541	265	1.69	S21 931630
H646	W962542	270	3.07	S21 931630
H647	W962543	275	4.09	S21 931630
H648	W962544	280	6.63	S21 931630
H649	W962545	285	6.05	S21 931630
H650	W962546	290	6.78	S21 931630
H651	W962547	295	5.68	S21 931630
H605	W962548	298	9.28	S21 950610
H523	W962549	305	8.82	S21 950610
H606	W962550	310	1.96	S21 950610

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS
H607	W962551	315	10.51	S21 950609
H608	W962552	320	10.29	S21 950608
H610	W962553	325	7.77	S21 950608
H611	W962554	330	10.08	S21 950608
H609	W962555	335	7.75	S21 949606
H524	W962556	342	9	S21 949606
H612	W962557	345	8.78	S21 948606
H613	W962558	350	8.24	S21 947606
H525	W962559	355	6.14	S21 946605
H631	W962560	360	5.92	S21 946605
H632	W962561	365	8.46	S21 946605
H614	W962562	370	6.93	S21 949606
H615	W962563	375	8.03	S21 949606
H616	W962564	380	6.61	S21 949606
H617	W962565	385	10.37	S21 949606
H618	W962566	390	5.9	S21 949606
H619	W962567	395	2.62	S21 949606
H620	W962568	400	1.08	S21 949606
H621	W962569	405	4.12	S21 949606
H622	W962570	410	2.12	S21 949605
H623	W962571	420	0.98	S21 949605
H624	W962572	425	1.04	S21 949605
H625	W962573	430	1.78	S21 949605
H626	W962574	435	1.82	S21 949605
H627	W962575	440	1.05	S21 949605
H628	W962576	445	1.8	S21 949605
H629	W962577	450	2.16	S21 949605
H630	W962578	455	4.08	S21 952604
H536	W962579	460	2.54	S21 952604
H642	W962580	465	3.66	S21 952604
H535	W962581	470	1.81	S21 952604
H641	W962582	475	1.14	S21 952604
H640	W962583	480	1.29	S21 952604
H534	W962584	485	1.8	S21 952604
H639	W962585	490	1.22	S21 952604
H533	W962586	495	1.41	S21 952604
H638	W962587	500	2.59	S21 952604
H532	W962588	510	4.17	S21 952604
H637	W962589	515	3.26	S21 952604
H531	W962590	520	4.78	S21 952604
H636	W962591	525	2.64	S21 952604

Sample Details for Mangapanian strata, Wanganui River Section				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PK1	961073	551	2.71	958582
PK2	961074	553	3.48	958582
PK3	961075	554	5.08	958582
PK4	961076	555.9	3.86	958582
PK5	961077	557.9	9.40	958582
PK6	961078	559.9	6.03	958582
PK7	961079	561.4	10.50	958582
PK9	961080	565.4	8.45	958582
PK10	961081	568.2	18.39	958582
PK11	961082	564.4	8.62	960582
PK12	961083	568.2	10.80	960582
PK13	961084	572.2	13.46	960582
PK14	961085	576.2	31.50	960582
PK15	961086	579.2	20.58	960582
PK16	961087	582.5	19.61	960582
PK17	961088	583.5	22.10	961583
PK18	961089	585.5	20.37	961583
PK19	961090	587.5	23.47	961583
PK20	961091	590	42.48	961583
PK21	961092	592	49.29	961583
PK22	961093	593	46.16	961583
PK23	961094			963583
PK24	961095			963583
PK25	961096			963583
PK26	961097			963583
PK27	961098	606.7	14.70	960580
PK28	961099	607.2	20.42	960580
PK29	961100	602.5	4.77	960580
PK30	961101	604.3	12.77	960580
PK31	961102	605.7	10.99	960580
PK32	961103	607.2	18.70	960580
PK33	961104	608.2	11.02	960580
PK34	961105	611.5	12.89	960580
PK35	961106	599.5	22.02	960580
PK36	961107	593	62.47	960580
PK37	961108	631.1	26.66	958574
PK38	961109			958574
PK39	961110	630.1	23.57	958574
PK40	961111	628.3	43.42	958574
PK41	961112	627.3	34.67	958574
PK42	961113	624.3	39.54	959575
PK43	961114	621.8	45.21	959575
PK44	961115	619.8	43.27	959575
PK45	961116	617.3	36.84	959575
PK46	961117	615	42.21	959575
PK47	961118	613	15.56	959575
PK48	961119	610.5	15.62	959575
PK49	961120			956573
PK50	961121			956573
PK51	961122			956573
PK52	961123			956573
PK53	961124			956573
PK54	961125			956573
PK55	961126			956573
PK56	961127	641	3.56	955572
PK57	961128	642.5	2.22	955572
PK58	961129	644	4.26	955572
PK59	961130	645.5	8.05	955572
PK60	961131	647	4.93	955572
PK61	961132	648.5	1.85	955572
PK62	961133	650	1.83	955572
PK63	961134	651.5	5.18	955572
PK64	961135	653	2.21	955572
PK65	961136	654.5	2.57	955572
PK66	961137	656	6.27	955572

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PK67				
PK68				
PK69				
PK70	961141	662	19.63	954572
PK71	961142	665	6.61	954572
PK72	961143	666.5	13.45	954572
PK73	961144	667.5	5.61	954572
PK74	961145	668.5	7.34	954572
PK75	961146	670	23.62	954572
PK76	961147	671.5	16.12	954572
PK77	961148	673	30.68	954572
PK78	961149	674.5	25.15	954572
PK79	961150	676	32.30	954572
PK80	961151	677.5	25.28	954572
PK81	961152	679	41.80	954572
PK82	961153	680.5	53.54	954572
PK83	961154	682	59.82	954572
PK84	961155	685.5	40.58	954572
PK85	961156	687.5	36.93	954572
PK86	961157	688.5	19.25	954572
PK87	961158	692.5	1.42	954572
PK88	961159	694.5	1.13	954572
PK89	961160	695.5	1.51	954572
PK90	961161	697.5	1.26	954572
PK91	961162	700	3.30	954572
PK92	961163	702	3.71	954572
PK93	961164	704	6.76	954572
PK94	961165	706	2.97	954572
PK95	961166	707.5	23.48	954572
PK96	961167	710	25.73	954572
PK97	961168	712.5	16.54	954572
PK98	961169	714.5	11.66	954572
PK99	961170	716.5	12.78	954572
PK100	961171	720.5		954572
PK101	961172	722.5		954572
PK102	961173	724.5		954572
PK103	961174	726.5		954572
PK104	961175	714.5	41.23	956572
PK105	961176	716.5	44.62	956572
PK106	961177	718.5	46.94	956572
PK107	961178	720	43.51	956572
PK108				956572
PK109	961180	723	17.41	956572
PK110	961181	725	16.83	956572
PK111	961182	727	27.22	956572
PK112	961183	729	30.83	956572
PK113	961184	731	46.42	956572
PK114	961185	733	50.20	956572
PK115	961186	735	33.14	956572
PK116	961187	736.5	21.72	956572
PK117				956572
PK118	961189	739	9.15	956572
PK119	961190	740.5	1.66	956572
PK120	961191	742	1.07	956572
PK121	961192	744	3.12	956572
PK122	961193	746	1.69	956572
PK123	961194			956572
PK124	961195	750	2.66	956572
PK125	961196	752	4.33	956572
PK126	961197	754	2.14	956572
PK127	961198	755.5	4.27	956572
PK128	961199	757.5	5.84	956572
PK129	961200	759.5	7.22	956572
PK130	961201	761.5	7.05	956572
PK131	961202	764.5	14.54	956572
PK132	961203	762.5	7.15	962572
PK133	961204	764.5	15.19	962572
PK134	961205	769.5	3.08	962572
PK135	961206	771	1.33	962572

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PK136	961207	783	59.31	962572
PK137	961208	785.5	17.20	962572
PK138	961209	794.5	12.95	962572
PK139	961210	796	25.63	962572
PK140				
PK141				
PK142				
PK143				
PK144				
PK145	961216	798	14.17	962572
PK146	961217	799.5	3.99	962572
PK147	961218	805.5	19.02	962572
PK148	961219	807.5	19.90	962572
PK149	961220	809	23.85	962572
PK150	961221	814.5	10.61	962572
PK151	961222	816	5.95	963570
PK152	961223	817.5	7.04	963570
PK153	961224	825	66.26	963570
PK154	961225	826.5	3.62	963570
PK155	961226	837.7	6.62	963570
PK156	961227	839.7	2.37	963570
PK157	961228	842.2	30.52	963570
PK158	961229			963570
PK159	961230	845	64.20	963570
PK160	961231	849	38.66	963570
PK161	961232	852	64.65	963570
PK162	961233	854	65.15	963570
PK163	961234	856	72.37	963570
PK164	961235	858.5	67.35	963570
PK165	961236	860.5	77.65	963570
PK166	961237	860.5	71.62	951546
PK167	961238	862.5	74.24	951546
PK168	961239	865	74.97	951546
PK169	961240	867	74.06	951546
PK170	961241	869.5	67.71	951546
PK171	961242	881.5	3.31	952548
PK172	961243	885	5.77	952548
PK173	961244	888.5	8.38	952548
PK174	961245	891.5	21.91	952548
PK175	961246	893.5	21.18	952548
PK176	961247	895.5	9.85	952548
PK177	961248	897.5	18.57	952548
PK178	961249	899.5	21.62	952548
PK179	961250	902.5	9.83	952548
PK180	961251	904.5	16.15	952548
PK181	961252	906.5	18.57	952548
PK182	961253	908.5	16.53	952548
PK183	961254	912	27.32	952548
PK184	961255	914	22.24	952548
PK185	961256	916	3.99	952548
PK186	961257	919	17.02	952548
PK187	961258	921	12.81	952548
PK188	961259	923	11.01	952548
PK189	961260	925	26.29	945543
PK190	961261	928.5	11.87	945543
PK191	961262	932.5	19.26	945543
PK192	961263	936	37.80	945543
PK193	961264	936.3	22.39	945543
PK194	961265	938.3	19.22	945543
PK195	961266	940	31.62	945543
PK196	961267	943	26.55	945543
PK197	961268	945	10.48	945543
PK198	961269	946	1.56	945543
PK199	961270	948.5	10.42	945543
PK200	961271	950	4.62	947543
PK201	961272	953.5	2.89	947543
PK202	961273	956	6.35	947543
PK203	961274	958	8.97	947543
PK204	961275	960.5	7.13	947543
PK205	961276	962.5	9.83	947543

Textural Sample Details for Mangapanian strata, Parihauhau Road				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PR200	97739	0	30.91	030617
PR201	97740	2	19.24	
PR202	97741	4	34.36	
PR203	97742	6	16.71	
PR204	97743	8	43.43	
PR205	97744	10	67.11	
PR206	97745	12	39.43	
PR207	97746	14	41.28	
PR208	97747	16	31.06	
PR209	97748	18	50.84	
PR210	97749	20	11.94	
PR211	97750	22	11.03	
PR212	97751	35	8.74	
PR213	97752	37	8.73	
PR214	97753	39	6.71	
PR215	97754	41	14.71	
PR216	97755	43	12.53	
PR217	97756	53	28.31	
PR218	97757	57	17.34	
PR219	97758	62		
PR220	97759	64	12.74	
PR221	97760	66	14.28	
PR222	97761	68	2.49	
PR223	97762	70	8.88	
PR224	97763	72	12.61	
PR225	97764	74	14.17	
PR226	97765	76	17.73	
PR227	97766	77	15.78	
PR228	97767	79	23.08	
PR229	97768	80	15.07	
PR230	97769	81	13.56	
PR231	97770	82	33.5	
PR232	97771	83	29.55	
PR233	97772	84	43.24	
PR234	97773	85	69.62	
PR235	97774	86	61.11	
PR236	97775	87	82.16	
PR237	97776	88	75.67	
PR238	97777	89	33.24	
PR239	97778	91	61.63	
PR240	97779	93	36.76	032609
PR400	97780	94	64.56	033607
PR401	97781	95	17.2	
PR403	97782	97	15.21	
PR404	97783	99	12.9	
PR405	97784	101	15.6	
PR406	97785	103	15.86	
PR407	97786	105	10.75	
PR408	97787	107	17.91	
PR409	97788	109	14.75	
PR410	97789	111	16.1	
PR411	97790	113	19.01	
PR412	97791	115	27.85	
PR413	97792	117	45.8	
PR414	97793	119	33.34	
PR415	97794	121	47.07	
PR416	97795	123	26.51	
PR417	97796	125	49.08	
PR418	97797	127	39.21	
PR419	97798	129	61.96	
PR420	97799	137	2.57	
PR421	97800	139	6.65	
PR422	97801	141	22.18	
PR423	97802	143	81.11	

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PR424	97803	145	76.14	
PR425	97804	147	78.78	
PR426	97805	149	47.71	
PR427	97806	151	55.11	
PR428	97807	152	48.01	
PR429	97808	154	91.68	029592
PR500	97809	160	18.65	023585
PR501	97810	162	30.65	
PR502	97811	164	32.53	
PR503	97812	166	28.84	
PR504	97813	168	26.41	
PR505	97814	170	33.05	
PR506	97815	179	28.6	
PR507	97816	181	36.29	
PR508	97817	183	38.8	
PR509	97818	185	44.06	
PR510	97819	187	41.94	
PR511	97820	190	64.79	
PR512	97821	192	60.45	028586
PA200	97822	199	67.88	984554
PA201	97823	204.5	21.27	
PA202	97824	206.5	18.42	
PA203	97825	208.5	9.57	
PA204	97826	210.5	4.89	
PA205	97827	212.5	5.22	
PA206	97828	214.5	6.68	
PA207	97829	216.5	6.46	
PA208	97830	218.5	4.33	
PA209	97831	220.5	13.8	
PA300	97832	229.5	32.56	
PA301	97833	231	25.64	
PA302	97834	235	32.52	
PA303	97835	237	32.86	
PA304	97836	239	39.5	
PA305	97837	244	90.79	
PA306	97838	246	89.54	
PA307	97839	248	90.08	
PA308	97840	250	87.16	
PA309	97841	252	90.65	
PA310	97842	254	86.03	
PA311	97843	256	90.75	
PA312	97844	258	86.73	
PA313	97845	260	89.06	
PA314	97846	262	93.93	
PA315	97847	264	91.22	
PA316	97848	266	93.07	
PA317	97849	268	92.78	
PA318	97850	270	91.74	
PA319	97851	272	92.02	
PA320	97852	274	93.96	
PA321	97853	276	92.44	
PA322	97854	278	89.99	
PA323	97855	281	93.77	
PA324	97856	283	95.25	981555

Textural Sample Details for Mangapanian strata, Whangehu River valley, Mangamahu				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
PC185	97933	0	14.01	126547
PC186	97934	2	29.79	
PC187	97935	10	35.56	
PC188	97936	12	39.03	
PC189	97937	14	63.33	
PC190	97938	16	80.93	
PC191	97939	18	77.02	
PC192	97940	20	79.42	
PC193	97941	22	81.19	
PC194	97942	22.5	47.77	
PC195	97943	23.5	84.21	
PC196	97944	24	34.57	
PC197	97945	25	35.04	
PC198	97946	27	43.38	
PC199	97947	27.5	51.94	
PC200	97948	28	48.19	
PC289	97949	31	26.56	
PC290	97950	36	34.15	
PC291	97951	41	33.39	
PC292	97952	43	43.91	
PC293	97953	45	30.5	
PC294	97954	47	37.84	
PC295	97955	49	32.58	
PC296	97956	51	34.13	
PC297	97957	53	39.97	
PC298	97958	55	44.38	
PC299	97959	57	50.27	
PC300	97960	61	52.29	125546
MR78	971120	75	76.9	134542
MR79	971121	77	86.17	
MR80	97961	79	32.74	
MR81	97962	81	38.89	
MR82	97963	83	38.85	
MR83	97964	85	48.32	
MR84	97965	87	46.26	
MR85	97966	89	48.44	
MR86	97967	91	67.38	
MR87	97968	95.5	73.18	
MR88	97969	97	36	
MR89	97970	99	10	
MR90	97971	101	5.45	
MR91	97972	103	6.37	
MR92	97973	105	10.06	
MR93	97974	107	9.01	
MR94	97975	109	14.01	
MR95	97976	111	19.73	
MR96	97977	113	17.88	
MR97	97978	115	33.55	
MR98	97979	117	16.99	134539
AC87	97980	121	29.73	126537
AC88	97981	123	37.97	
AC89	97982	125	28.5	
AC90	97983	127	32.38	
AC91	97984	129	39.6	
AC92	97985	131	19.82	
AC93	97986	133	35.2	
AC94	97987	135	30.24	
AC95	97988	137	48.12	
AC96	97989	139	34.13	
AC97	97990	141	41.63	
AC98	97991	143	42.7	
AC99	97992	145	41.64	

Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
AC200		146.5	10.09	
AC201	97993	148.5	6.37	
AC202	97994	150.5	7.75	
AC203	97995	152.5	3	
AC204	97996	154.5	0.26	
AC205	97997	156.5	7.86	
AC206	97998	158.5	3.73	
AC207	97999	160.5	7.97	127536
CR100	971002	209	4.63	154529
CR101	971003	215	18.96	
CR102	971004	221	82.33	
CR103	971005	222	65.67	
CR104	971006	223.5	32.35	
CR105	971007	225.5	32.78	
CR106	971008	227.5	27.25	
CR107	971009	229.5	62.82	
CR108	971010	231.5	42.17	152529
PC600	971011	235	2.71	116531
PC601	971012	238	3.26	
PC602	971013	246	31.3	
PC603	971014	256	35.2	
PC604	971015	260	25.97	
PC605	971016	264	62.85	
PC606	971017	266.5	70.9	
PC607	971018	272.5	74.31	
PC786	971019	278.5	2.05	
PC787	971020	280.5	1.82	
PC788	971021	282.5	2.22	
PC789	971022	284.5	2.09	
PC790	971023	286.5	6.21	
PC791	971024	288.5	4.09	
PC792	971025	290.5	3.87	
PC793	971026	292.5	12.27	
PC794	971027	294.5	8.14	
PC795	971028	296.5	11.94	
PC796	971029	298.5	3.17	
PC797	971030	300.5	9.7	
PC798	971031	302.5	8.46	
PC799	971032	304.5	10.01	
PC800	971033	306.5	25.07	
PC801	971036	308.5	52.88	
PC802	971037	314.5	21.33	115530
MR800	971038	321	6.55	122523
MR801	971039	323	9.87	
MR802	971040	325	12.63	
MR803	971041	327	23.12	
MR804	971042	329	18.56	
MR805	971043	331	23.69	
MR806	971044	333	17.21	
MR807	971045	336	30.2	
MR808	971046	337	24.73	
MR809	971047	340	4.7	122520

Textural Sample Details for Mangapanian strata, Turakina valley				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
TR1	97857	0	14.57	226528
TR2	97858	15	48.49	
TR3	97859	17	49.16	
TR4	97860	19	39.76	
TR5	97861	24	39.79	
TR6	97862	26.5	38.47	
TR7	97863	28.5	24.85	
TR8	97864	30	25.61	
TR9	97865	32	28.96	
TR10	97866	34	34.19	
TR11	97867	36	49.46	
TR12	97868	38	63.5	
TR13	97869	40	74.04	
TR14	97870	42	67.2	
TR15	97871	44	75.41	
TR16	97872	46		227524
TR100	97873	64	18.83	218519
TR101	97874	66	26.59	
TR102	97875	68	25.35	
TR104	97876	70	28.36	
TR105	97878	72	26.77	
TR106	97879	74	28.99	
TR107	97880	94	43.17	
TR108	97881	96	51.55	
TR109	97882	98	77.51	
TR179	97883	100	10.23	
TR180	97884	102	7.48	
TR181	97885	104	5.68	
TR182	97886	106	6.78	
TR183	97887	108	13.99	
TR184	97888	110	21.77	
TR185	97889	112	82.53	
TR186	97890	114	84.22	
TR187	97891	116	85.4	
TR188	97892	118	84.59	
TR189	97893	120	85.35	
TR190	97894	122	84.52	
TR191	97895	124	86.6	
TR192	97896	126	87.32	
TR193	97897	128	80.92	
TR194	97898	130	34.42	
TR195	97899	132	30.63	
TR196	97900	134	18.73	
TR197	97901	136	15.91	
TR198	97902	137	26.89	
TR199	97903	139	30.67	
TR200	97904	141	57.62	217519
TR498	971034	159	91.2	230504
TR499	971035	161	85.98	
TR500	97905	169.5	30.52	
TR501	97906	171.5	30.62	
TR502	97907	173.5	33.15	
TR503	97908	175.5	39.05	
TR504	97909	177.5	43.17	
TR505	97910	179.5	29.54	
TR507	97911	181.5	38	
TR508	97912	183.5	54.16	
TR509	97922	187.5	39.43	
TR510	97923	191.5	80.66	
TR511	97924	193.5	82.38	
TR512	97925	195.5	77.22	
TR513	97926	197.5	84.51	231499
TR600	97927	199.5	65.79	230500
TR601	97928	202.5	66.15	
TR602	97929	204.5	50.59	
TR603	97930	207	42.79	
TR604	97931	212	63.47	
TR605	97932	222	47.26	232498

Textural Sample Details for Mangapanian strata, West Road section, Porewa valley, Rangitikei				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS T22
WEST79	971074	0	23.26	347475
WEST80	971075	15	16.42	
WEST81	971076	40	79.99	
WEST82	971077	80	83.68	
WEST83	971078	95	80.79	
WEST84	971079	100	54.99	
WEST85	971080	105	36.73	
WEST86	971081	110	11.32	
WEST87	971082	111	11.06	
WEST88	971083	112	25.66	
WEST89	971084	114	73.16	
WEST90	971085	124	71.04	
WEST91	971086	134	77.65	
WEST92	971087	139	84.65	
WEST93	971088	143	85.49	
WEST94	971089	145	17.2	
WEST95	971090	148	15.32	
WEST96	971091	166	6.73	
WEST97	971092	169	20.55	
WEST98	971093	174	3.57	
WEST99	971094	186	9.34	
WEST100	971095	189	16.83	331482

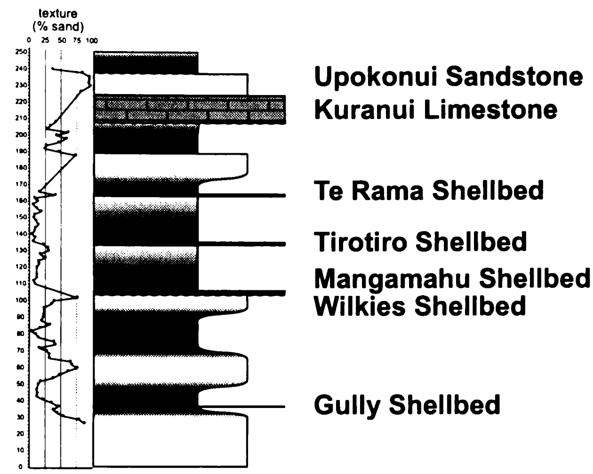
Textural Sample Details for Mangapanian strata, Watershed road section, between Porewa and Rangitikei valleys				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS T22
WR0	971096	0	24.48	388518
WR0a	971097	4	20.36	
WR1	971098	8	29.43	
WR2	971099	18	46.83	
WR3	971100	20	7.99	
WR4	971101	40	16.2	
WR5	971102	50	29.23	
WR6	971103	70	34.07	
WR7	971104	82	9.02	
WR8	971105	85	8.35	
WR9	971106	95	18.4	
WR10	971107	99	34.01	
WR11	971108	103	36.36	
WR12	971109	123	69.99	
WR14	971110	135	54.16	
WR15	971111	138	8.85	
WR16	971112	133	65.92	
WR17	971113	136.5	8.98	
WR18	971114	145.5	6.41	
WR19	971115	150.5	12.17	
WR20	971116	160.5	7.36	
WR29	971117	180.5	2.04	
WR30	971118	182.5	10.08	
WR31	971119	184	15.22	371473

Textural Sample Details for Mangapanian strata, Rangitikei River valley (TJ*** series samples from Journeaux, 1995).				
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
TJ36	95474	4	84	505568
TJ37	95475	12	92	505568
TJ38	95476	20	70	505568
TJ39	95477	22	92	505568
TJ40	95478	24	90	505568
TJ41	95479	28	82	505568
TJ42	95480	30	88	505568
TJ43	95481	33	75	505568
TJ44	95482	37	79	505568
TJ45	95483	42	66	505568
TJ46	95484	46	37	505568
TJ47	95485	51	16	508522
TJ48	95486	57	19	508522
TJ49	95487	63	22	508521
TJ50	95488	68	29	509520
TJ51	95489	75	31	509520
TJ52	95490	83	37	510519
TJ53	95491	90	19	510519
TJ54	95492	97	31	511519
TJ55	95493	104	35	511519
TJ56	95494	110	31	511519
TJ57	95495	117	24	512519
TJ58	95496	126	19	512519
TJ59	95497	134	10	515515
TJ60	95498	139	9	515515
TJ61	95499	144	10	516514
TJ62	95500	149	15	516514
TJ63	95501	154	5	516513
TJ64	95502	160	7	516513
TJ65	95503	163	6	517512
TJ66	95504	170	6	517512
TJ67	95505	175	15	517511
TJ68	95506	180	29	517511
TJ69	95507	183	32	518510
TJ70	95508	189	22	518510
TJ71	95509	195	39	518509
TJ72	95510	199	37	518509
TJ73	95511	202	41	519508
TJ74	95512	207	38	519508
TJ75	95513	213	33	520508
TJ76	95514	220	32	520508
TJ77	95515	226	31	521508
TJ78	95516	230	33	521508
TJ79	95517	234	20	508513
TJ80	95518	240	9	508513
TJ81	95519	244	10	508513
TJ82	95520	250	8	508513
TJ83	95521	254	6	508513
TJ84	95522	259	8	509513
TJ85	95523	263	40	509513
TJ86	95524	270	29	509513
TJ87	95525	273	31	509513
TJ88	95526	280	16	509513
TJ89	95527	286	26	487502
TJ90	95528	290	10	487501
TJ91	95529	296	6	487501
TJ92	95530	300	5	487500
TJ93	95531	306	6	486499
TJ94	95532	309	30	485497
TJ95	95533	313	28	485496
TJ96	95534	320	19	483496
TJ97	95535	323	33	483495
TJ98	95536	333	25	482497
TJ99	95537	339	22	482498
TJ100	95538	344	19	482499

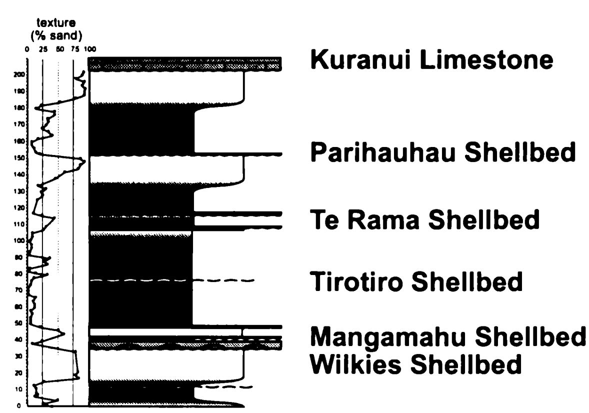
Field code #	Uni. of Waikato. Sample #	Thickness (m)	Sand (vol%)	Grid ref. NZMS S22
TJ101	95539	350	16	482501
TJ102	95540	358	12	482502
TJ103	95541	367	26	491489
TJ104	95542	374	27	490485
TJ105	95543	381	19	489482
TJ106	95544	389	9	487480
TJ107	95545	397	12	483479
TJ108	95546	402	25	481475
TJ109	95547	408	18	476475
TJ110	95548	417	28	476475
TJ111	95549	424	3	476475
TJ112	95550	433	6	467472
TJ113	95551	439	15	467472
TJ114	95552	446	3	467472
TJ115	95553	453	3	467472
TJ116	95554	458	8	467472

Textural Sample Details for Mangapanian strata, Rangitikei River valley (WKR*** series samples from Naish, 1996).				
Field code #	Uni. of Waikato. Sample #	Thickness	sand%	
WKR54	96326	96661	97	
WKR55/70	96325	96660	89	
WKR56	96324	96659	67	
WKR77	96323	96658	79	
WKR78	96322	96657	64	
WKR79	96321	96656	75	
WKR80	96320	96655	90	
WKR81	96319	96654	62	
WKR82	96318	96653	49	
WKR83	96317	96652	43	
WKR84	96316	96651	29	
WKR86	96315	96650	8	
WKR87	96314	96649	2	
WKR88	96313	96648	1	
WKR89	96312	96647	2	
WKR90	96311	96646	10	
WKR92	96310	96645	69	
WKR110	96309	96644	32	
WKR175	96308	96643	10	
WKR93	96307	96642	11	
WKR94	96306	96641	23	
WKR95	96305	96640	39	
WKR96	96304	96639	44	
WKR4	96303	96638	82	
WKR1	96302	96637	86	
WKR2	96301	96636	83	
WKR3	96300	96635	95	

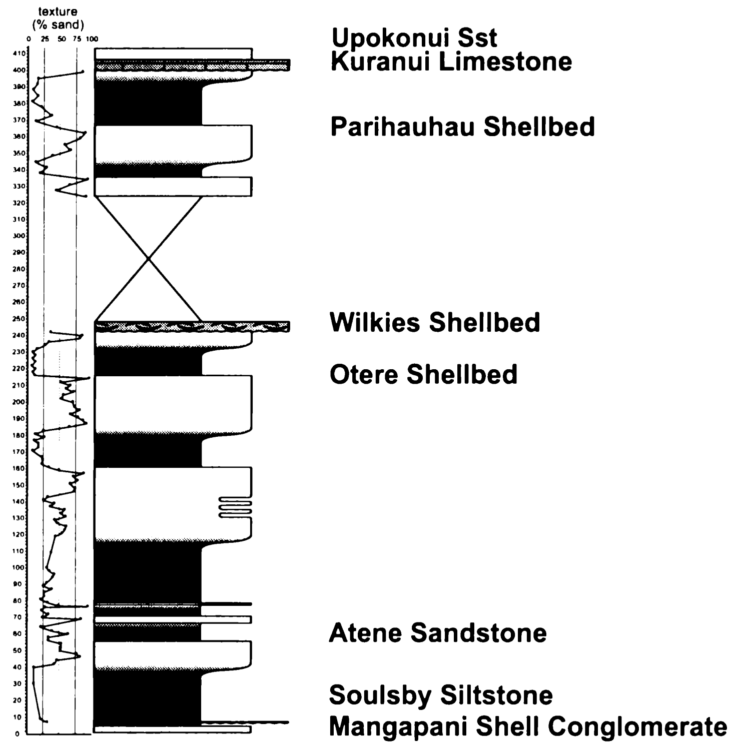
Textural properties of Mangapanian and early Nukumaruan strata, Rangitatau West Road (Okiwa) section.



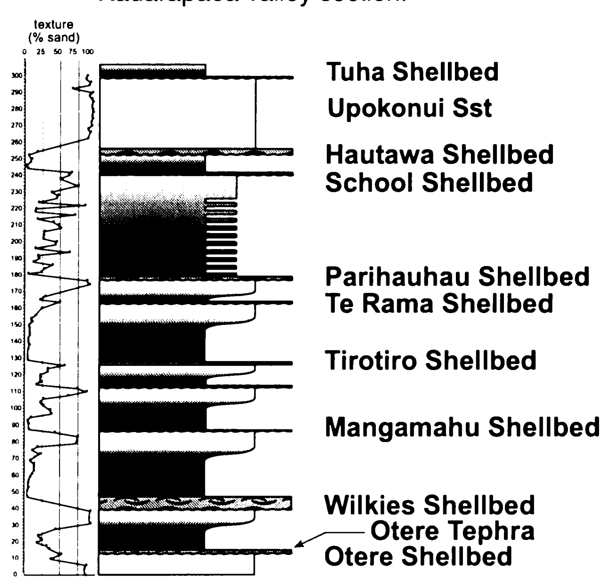
Textural properties of Mangapanian strata, Rangitatau East Road (Paparangi) section.



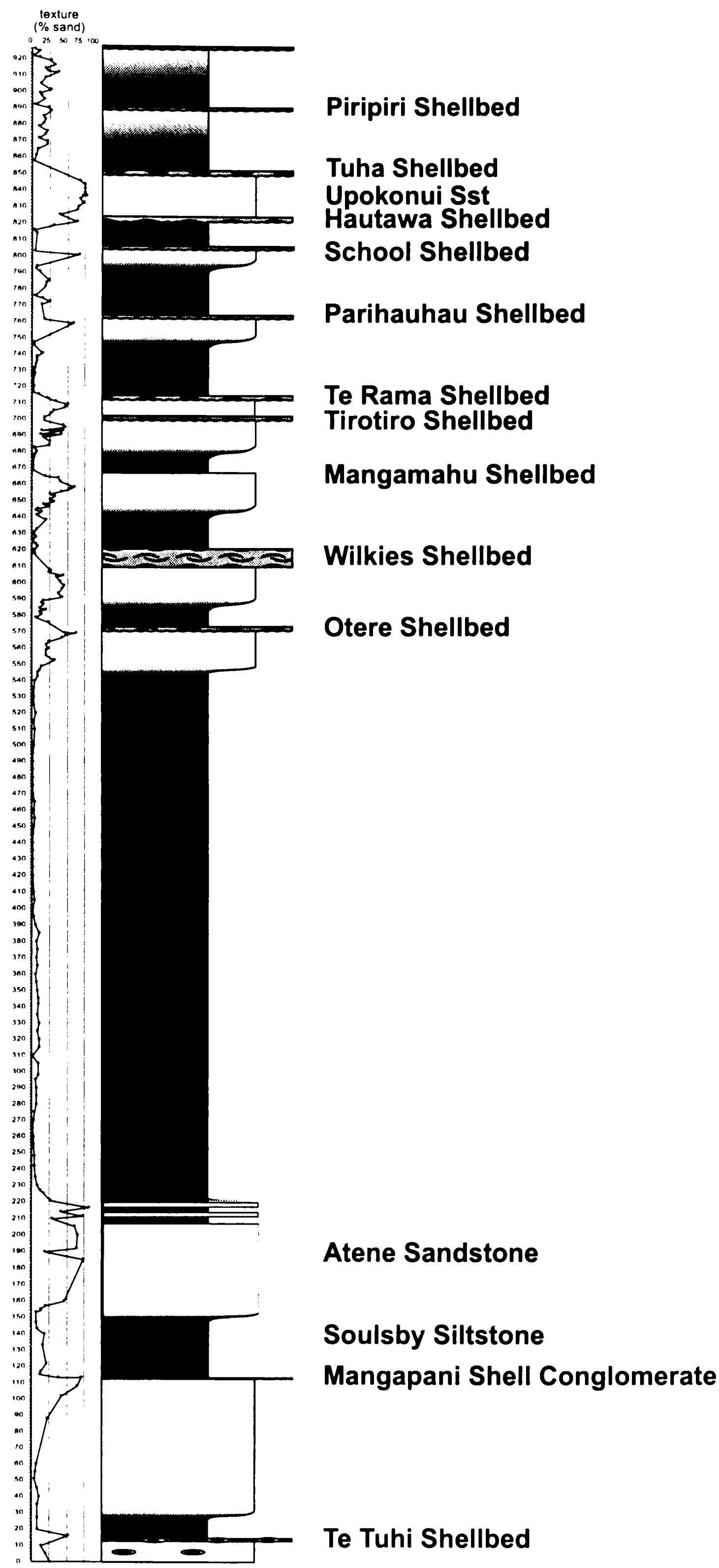
Textural properties of Mangapanian strata, Wairangi section.



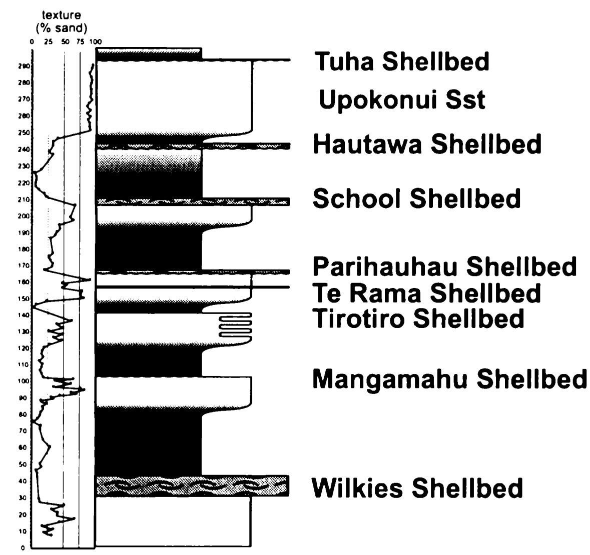
Textural properties of Mangapanian and early Nukumaruan strata, Kauarapaoa valley section.



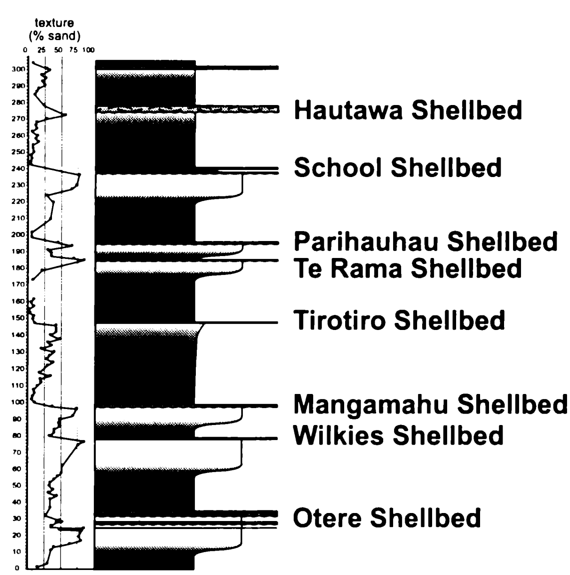
Textural properties of late Waipipian, Mangapanian and early Nukumaruan strata, Wanganui River valley section.



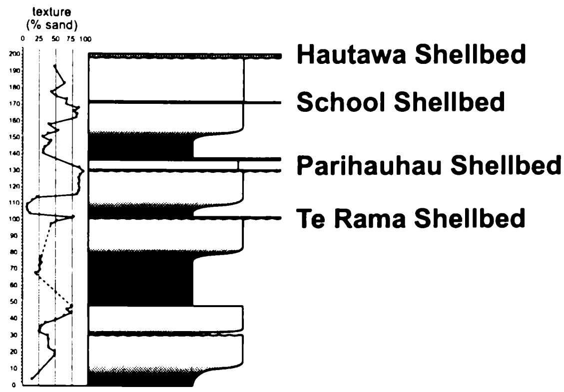
Textural properties of Mangapanian and early Nukumaruan strata, Parihauhau section.



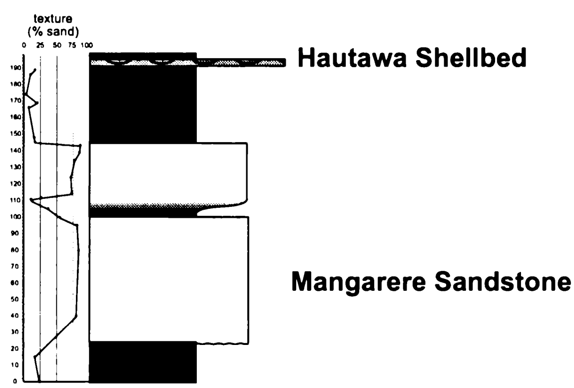
Textural properties of Mangapanian and early Nukumaruan strata, Whangaehu River valley (Mangamahu) section.



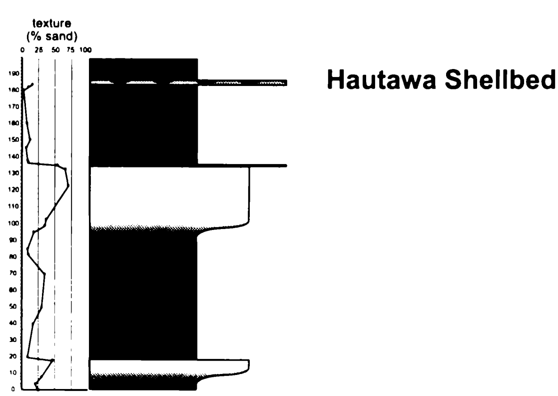
Textural properties of Mangapanian strata, Turakina River valley.



Textural properties of Mangapanian strata, Porewa valley (West Road) section.



Textural properties of Mangapanian strata, Watershed Road section.



APPENDIX TWO:

FOSSIL COLLECTIONS.

The following fossil lists include data from collections made in this region prior to this study, and are referenced as such. GS collections are from Fleming (1953), and the names of taxa have been updated to reflect modern usage where nessecary (e.g. *Baryspira* to *Amalda*). Fossil lists from Fleming (1953), Laws (1940), Naish, (1996) and Cater (1972) only record the presence of a species at each site, and so data from these studies is marked by an "x" in the lists. Collections made in this study attempt to are semi-quantitative, and are broadly classified into abundant (a, > 15 %), common (c, 5 - 15 %) and rare (r, < 5%) for each site. The position of the species within the collected unit is also recorded as either lower (l), upper (u) or throughout (t). Fossils noted in the field but not collected are marked (f). Thus, the code "l - a" means that the fossil is abundant in the lower part of the unit. Similarly, "t - r (f)" means that the fossil is found throughout the unit, but is rare, and has not been collected from this site. The columns with grey backgrounds refer to collections made at the type locality of the unit in question

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MANGAPANI SHELL CONGLOMERATE						
	apm1	apm3	apm2	apm2	apm3	apm3
	SH3	**Waitot.**	Waitot.	Waitot.	**Waitot.**	**Waitot.**
		Laws '40	GS 4216	Roadside	**GS 4227**	
Nucula nitidula Adams, 1856.		x				
Glycymeris waipipiensis (Marwick, 1923).			x		x	
Glycymeris (Glycymerula) modesta (Angas, 1879).		x				
Tucetona laticostata (Quoy & Gaimard, 1835).					x	l - c
Perna canaliculus (Gmelin, 1791).			x		x	
Modilus areolatus (Gould, 1850).						
Atrina pectinata zelandica (Gray, 1835).						
Chlamys gemmulata (Reeve, 1853).						
Phialopecten thomsoni Marwick, 1965.	t - r	x	x	t - a	x	u - a
Anomia trigonopsis Hutton, 1877.			x		x	
Patro undatus Gray, 1850.		x		l - c		
Limatula maoria Finlay, 1926.						
Crassostrea ingens (Zittel, 1864).				u - r	x	
Ostrea chilensis lutaria (Hutton, 1873).	t - c					
Divaricella huttoniana (Vanatta, 1901).						
Arthritica dispar Laws, 1940.		x				
Pachykellia concentrica Powell, 1927.		x			x	
Puyseguria wanganuica Powell, 1931.		x				
Purpurocardia purpurata (Deshayes, 1854).					x	
Condylocuna dupliora (Laws, 1940).		x				
Maoricardium spatiosum (Hutton, 1873).			x	u - r	x	l - c
Pratulum sp.						
Cyclomactra aff. *tristis* (Reeve, 1854).						
Mactra aff. *discors* Gray, 1837.					x	
Mactra (Mactiona) mula Marwick, 1948.				l - r		
Scalpomactra scalpellum (Reeve, 1854).		x				
Spisula (Crassula) aff. *aequilatera* (Deshayes, 1854)		x		l - c	x	
Lutraria solida Hutton, 1873.			x	l - c	x	
Paphies crassiformis (Marshall & Murdoch, 1920).					x	
Paphies australis (Gmelin, 1791).		x	x		x	
Paphies sp.			x			
Gari (Gobraeus) stangeri (Gray, 1843).		x		l - a	x	
Dosina zelandica Gray, 1835.					x	
Austrovenus crassitesta (Finlay, 1924).		x			x	
Tawera subsulcata (Suter, 1905).		x	x	l - r	x	
Dosinia (Kereia) aff. (n.sp?) *greyi Zittel, 1864.*						
Eumarcia plana Marwick, 1927.		x	x	l - a	x	l - c
Eumarcia (Atamarcia) benhami Marwick, 1927.		x			x	
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).						
Caryocorbula zelandica (Quoy & Gaimard, 1835).		x				
Myadora subrostrata Smith, 1880.		x				
*Micrelench*us aff. *sanguineus sanguineus* Gray, 1843.		x			x	
Trochus (Coelotrochus) tiaratus Quoy & Gaimard, 1834.		x			x	
Zethalia coronata (Marwick, 1948).		x	x	l - a	x	
Calliostoma hodgei Hutton, 1875.		x				
Calliostoma aff. *wanganuicum* Oliver, 1926.					x	
Calliostoma sp.						l - r
Fautor sp. ?					x	
Anabathron (Scrobs) kaawaensis (Laws, 1936).		x				
Pisinna missile (Laws, 1940).		x				
Pisinna seminsulcata (Hutton,1885).					x	
Elachorbis unicarina Laws, 1940.		x				
Zeacumantus lutulentus (Keiner, 1842).		x			x	
Maoricolpus roseus (Quoy & Gaimard, 1834)		x	x	l - a		l - r
Pelicaria n.sp. aff. *zelandiae* (Marshall & Murdoch, 1920)						
Struthiolaria ?errata? Marwick, 1924.				l - r		
Struthiolaria sp.				l - r		
Crepidula radiata (Hutton, 1873).		x	x	t - c		l - r
Sigapatella novaezelandiae (Lesson, 1830).		x	x	t - c	x	l - r
Zegalerus crater Finlay, 1926.			x		x	
Zegalerus tenuis (Gray, 1867).		x				
Mipliodерma mangawera (Laws, 1940).		x				
Trichosirius cavatocarinatus (Laws, 1940).		x				
Taniella aff. *planisutularis* (Marwick, 1924).		x			x	

Polinices sp.		x			
Polinices waipipiensis (Marwick, 1924).		x	x	l - a	x
Selia (Hebeselia) bulbosa (Suter, 1908).		x			
Specula cf. *retifera* (Suter, 1908).		x			
Funiscala nympha (Hutton, 1885).		x			
Austrofusus pliocenicus (Powell, 1931).		x		l - c	x
Buccinulum sp.					x
Cominella excoriata (Finlay, 1926).					x
Cominella (Josepha) glandiformis (Reeve, 1847).				l - r	
Penion aff. *cuvierianus* (Powell, 1927).					
Penion sulcatus (Lamark, 1816).					
"Zafra" impedita Laws, 1940.		x			x
Paratrophon n.sp. aff. *quoyi cheesmani* (Hutton, 1882).		x			x
Xymene ambiguus (Phillipi, 1844).		x			x
Xymene bonneti bonneti (Cossman, 1903).		x			x
Xymene "drewi" (Hutton)				l - c	x
Thais cf. *orbita* (Gmelin, 1791).				l - c	
Amalda (Baryspira) australis (Sowerby, 1830).		x			x
Amalda (Baryspira) oraria (Olson, 1956).			x		
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).				l - a	
Alcithoe arabica (Gmelin, 1791).					
Alcithoe whakinoensis Marwick, 1926.		x			x
Alcithoe sp.					
Duplicaria (Pervicacia) tristis (Deshayes, 1859).		x			
Phenatoma rosea (Quoy & Gaimard, 1833).		x			
Neoguraleus sinclair (Smith, 1884).		x			
Evalea liricinta (Suter, 1907).		x			
Gumina minor Laws, 1940.		x			
Linopyrga rugata (Hutton, 1884).		x			
Odostomia zecorpulenta Laws, 1939.		x			
Odostomia sp.		x			
Chemnitzia petaneana Laws, 1937.		x			
Eulimella deplexa Hutton, 1885.		x			x
Eulimella levirata Murdoch & Suter, 1906.		x			
Fissidentalium zelandicum (Sowerby, 1860).				l - r	
Neothyris aff. *ovalis* (Hutton)					
Neothyris sp.					
Waltonia inconspicua (Sowerby).					
Magasella sanguinea (Leach).					
Fellaster zelandiae (Gray).				l - c	
Pebbles				t - a	

MANGAPANI SHELL CONGLOMERATE					
		apm1		apm20	apm35
	Waitot.	Waitot.	Waitot.	Wairangi	Wanganui
	GS 4230	GS 4251	GS 4256		
Nucula nitidula Adams, 1856.					
Glycymeris waipipiensis (Marwick, 1923).					
Glycymeris (Glycymerula) modesta (Angas, 1879).					
Tucetona laticostata (Quoy & Gaimard, 1835).	x				
Perna canaliculus (Gmelin, 1791).		u - x (f)			
Modilus areolatus (Gould, 1850).		x			
Atrina pectinata zelandica (Gray, 1835).					u - r
Chlamys gemmulata (Reeve, 1853).		x	x	t - c	t - r
Phialopecten thomsoni Marwick, 1965.			x		
Anomia trigonopsis Hutton, 1877.					
Patro undatus Gray, 1850.		l - x	x		
Limatula maoria Finlay, 1926.		l - x			
Crassostrea ingens (Zittel, 1864).		u - x	x	u - c	
Ostrea chilensis lutaria (Hutton, 1873).		u - x	x	t - c	t - r
Divaricella huttoniana (Vanatta, 1901).				l - r	l - r
Arthritica dispar Laws, 1940.					
Pachykellia concentrica Powell, 1927.					
Puyseguria wanganuica Powell, 1931.					
Purpurocardia purpurata (Deshayes, 1854).		x	x		
Condylocuna dupliora (Laws, 1940).					
Maoricardium spatiosum (Hutton, 1873).	x				
Pratulum sp.					u - c
Cyclomactra aff. *tristis* (Reeve, 1854).		x			
Mactra aff. *discors* Gray, 1837.					
Mactra (Mactiona) mula Marwick, 1948.					
Scalpomactra scalpellum (Reeve, 1854).					
Spisula (Crassula) aff. *aequilatera* (Deshayes, 1854)					
Lutraria solida Hutton, 1873.					
Paphies crassiformis (Marshall & Murdoch, 1920).					
Paphies australis (Gmelin, 1791).					
Paphies sp.					
Gari (Gobraeus) stangeri (Gray, 1843).					
Dosina zelandica Gray, 1835.					
Austrovenus crassitesta (Finlay, 1924).					
Tawera subsulcata (Suter, 1905).		x			
Dosinia (Kereia) aff. (n.sp?) *greyi Zittel, 1864.*				l - r	
Eumarcia plana Marwick, 1927.					
Eumarcia (Atamarcia) benhami Marwick, 1927.					
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).		x			
Caryocorbula zelandica (Quoy & Gaimard, 1835).				u - r	
Myadora subrostrata Smith, 1880.					
*Micrelench*us aff. *sanguineus sanguineus* Gray, 1843.					
Trochus (Coelotrochus) tiaratus Quoy & Gaimard, 1834.					
Zethalia coronata (Marwick, 1948).					
Calliostoma hodgei Hutton, 1875.					
Calliostoma aff. *wanganuicum* Oliver, 1926.					
Calliostoma sp.					
Fautor sp. ?					
Anabathron (Scrobs) kaawaensis (Laws, 1936).					
Pisinna missile (Laws, 1940).					
Pisinna seminsulcata (Hutton,1885).					
Elachorbis unicarina Laws, 1940.					
Zeacumantus lutulentus (Keiner, 1842).					
Maoricolpus roseus (Quoy & Gaimard, 1834)	x			u - r	
Pelicaria n.sp. aff. *zelandiae* (Marshall & Murdoch, 1920)				u - r	t - r
Struthiolaria ?errata? Marwick, 1924.					
Struthiolaria sp.					
Crepidula radiata (Hutton, 1873).		x	x		
Sigapatella novaezelandiae (Lesson, 1830).		u - x (f)			
Zegalerus crater Finlay, 1926.		x			
Zegalerus tenuis (Gray, 1867).					
Miplioderma mangawera (Laws, 1940).					
Trichosirius cavatocarinatus (Laws, 1940).					
Taniella aff. *planisutularis* (Marwick, 1924).					

Polinices sp.					
Polinices waipipiensis (Marwick, 1924).				t - r	
Selia (Hebeselia) bulbosa (Suter, 1908).					
Specula cf. *retifera* (Suter, 1908).					
Funiscala nympha (Hutton, 1885).					
Austrofusus pliocenicus (Powell, 1931).					
Buccinulum sp.					
Cominella excoriata (Finlay, 1926).					
Cominella (Josepha) glandiformis (Reeve, 1847).					
Penion aff. *cuvierianus* (Powell, 1927).		x			
Penion sulcatus (Lamark, 1816).					t - r
"Zafra" impedita Laws, 1940.					
Paratrophon n.sp. aff. *quoyi cheesmani* (Hutton, 1882).					
Xymene ambiguus (Phillipi, 1844).					
Xymene bonneti bonneti (Cossman, 1903).					
Xymene "drewi" (Hutton)					
Thais cf. *orbita* (Gmelin, 1791).					
Amalda (Baryspira) australis (Sowerby, 1830).					
Amalda (Baryspira) oraria (Olson, 1956).	x	x		t - r	
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).					
Alcithoe arabica (Gmelin, 1791).			x		
Alcithoe whakinoensis Marwick, 1926.					
Alcithoe sp.					u - r
Duplicaria (Pervicacia) tristis (Deshayes, 1859).					
Phenatoma rosea (Quoy & Gaimard, 1833).					
Neoguraleus sinclair (Smith, 1884).					
Evalea liricinta (Suter, 1907).					
Gumina minor Laws, 1940.					
Linopyrga rugata (Hutton, 1884).					
Odostomia zecorpulenta Laws, 1939.					
Odostomia sp.					
Chemnitzia petaneana Laws, 1937.					
Eulimella deplexa Hutton, 1885.					
Eulimella levirata Murdoch & Suter, 1906.					
Fissidentalium zelandicum (Sowerby, 1860).					
Neothyris aff. *ovalis* (Hutton)		x			
Neothyris sp.				u - r?	
Waltonia inconspicua (Sowerby).		x			
Magasella sanguinea (Leach).		x			
Fellaster zelandiae (Gray).					
Pebbles				t - a	

GULLY SHELLBED		
		apm6
	Okiwa	**Okiwa**
	GS 4244	
Aulacomya ater maoriana (Iredale, 1915).	x	
Chlamys gemmulata (Reeve, 1853).	x	
Phialopecten thomsoni Marwick, 1965.	x	
Patro undatus Gray, 1850.	x	
Crassostrea ingens (Zittel, 1864).	x	**u - c (f)**
Ostrea chilensis lutaria (Hutton, 1873).		**u- c (f)**
Maoricardium spatiosum (Hutton, 1873).	x	
Lutraria solida Hutton, 1873.	x	
Maoricolpus roseus (Quoy & Gaimard, 1834)	x	

OTERE SHELLBED					
	apm22			apm36	apm55
	Kauarapaoa	Kauarapaoa	Kauarapaoa	**Wanganui**	Whangaehu
		GS 4221	GS 4222		
Chlamys gemmulata (Reeve, 1853).	t - c	x	x	**u - c**	
Phialopecten thomsoni Marwick, 1965.	l - r (f)				
Patro undatus Gray, 1850.		x	x		
Limatula maoria Finlay, 1926.			x		
Ostrea chilensis lutaria (Hutton, 1873).	t - c			**u - c**	
Divaricella huttoniana (Vanatta, 1901).		x			
Purpurocardia purpurata (Deshayes, 1854).	l - a		x	**t - a**	
Dosinia sp.	l - r?				l - r
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).		x	x		
Ruditapes sp.					l - c
Myadora striata (Quoy & Gaimard, 1835).			x		
Maoricolpus roseus (Quoy & Gaimard, 1834)	u - c	x			
Stiracolpus sp.		x			
Pelicaria n.sp. aff. *zelandiae* (M & M, 1920)		x			
Crepidula radiata (Hutton, 1873).	u - a			**t - r**	
Sigapatella novaezelandiae (Lesson, 1830).		x			
Taniella planisutularis (Marwick, 1924).		x			
Aeneator sp.		x			
Penion sp.		x			
Amalda (Baryspira) mucronata (Sowerby, 1830).		x			
Amalda (Baryspira) oraria (Olson, 1956).	u - c				
Neothyris sp.	u - c (f)		x		

WILKIES SHELLBED							
		apm14		apm21			
	Okiwa	Paparangi	Paparangi	Wairangi	Wairangi	Wairangi	
	GS 4226		GS 4209		GS 4211	GS 4213	
Cosa trigonopsis (Hutton, 1885).							
Tucetona laticostata (Quoy & Gaimard, 1835).							
Modiolus areolatus (Gould, 1850).	x		x				
Atrina pectinata zelandica (Gray, 1835).				u - c			
Chlamys gemmulata (Reeve, 1853).	x	t - a	x	t - a	x	x	
Phialopecten thomsoni Marwick, 1965.		l - r (f)	x	u - r			
Anomia trigonopsis Hutton, 1877.				l - c	x		
Patro undatus Gray, 1850.		l - c	x	u - c			
Limaria orientalis (A. Adams & Reeve, 1850).						x	
Limatula maoria Finlay, 1926.	x		x	u - r		x	
Crassostrea ingens (Zittel, 1864).		t - a (f)	x	u - a			
Ostrea chilensis lutaria (Hutton, 1873).	x	l - c (f)	x			x	
Divaricella huttoniana (Vanatta, 1901).	x						
Pteromyrtea dispar (Hutton, 1873).							
Mylitella finlayi (Marwick, 1924).	x						
Melliteryx parva (Deshayes, 1857).							
Purpurocardia purpurata (Deshayes, 1854).	x	l - c	x	t - a		x	
Hamacuna nukumaruensis (Laws, 1940).	x						
Volupicuna laqueus (Finlay, 1926)	x						
Trachycardium (Ovicardium) rossi Marwick, 1944.					x	x	
Pratulum pulchellum (Gray, 1843).							
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972.)				l - r			
Maorimactra sp.	x						
Lutraria solida Hutton, 1873.							
Gari (Gobraeus) stangeri (Gray, 1843).	x						
Dosina n.sp.				l - r			
Bassina yatei (Gray, 1835).	x		x				
Tawera subsulcata (Suter, 1905).	x						
Dosinia (Asa) lambata (Gould, 1850).							
Dosinia (Phacosoma) subrosea (Gray, 1835).				?u - r?			
Dosinia (Raina) cf. *nukumaruensis* (Marwick, 1927).			x				
Dosinia sp.	x						
Eumarcia plana Marwick, 1927.	x		x				
Panopea zelandica (Quoy & Gaimard, 1835).			x				
Barnea (Anchomasa) similis (Gray, 1835).				l - r			
Emarginula striatula Quoy & Gaimard, 1834.				l - r			
Tugali sp.			x				
Crossea (Crosseola) waitotara (Laws, 1940).							
Zethalia zelandica (Hombron & Jacquinot, 1854).	x						
Argalista fluctuata (Hutton, 1883).							
Attenuata charassa (Finlay, 1924).							
Merelina sp.							
Pisinna seminsulcata (Hutton,1885).	x						
Maoricolpus roseus (Quoy & Gaimard, 1834)				u - c			
Stiraclopus propagada Laws, 1940.			x				
Stiracolpus huttoni huttoni (Cossman, 1912).	x						
Stiracolpus sp.				u - r			
Zeacolpus sp.			x				
Pelicaria n.sp. aff. *zelandiae* (Marshall & Murdoch, 1920).			x				
Crepidula radiata (Hutton, 1873).	x	l - c (f)	x	t - a			
Sigapatella novaezelandiae (Lesson, 1830).			x	l - c			
Zegalerus cf. crater Finlay, 1926.	x					x	
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).	x						
Polinices aff. *waipipiensis* (Marwick, 1924).			x				
Selia (Lyroselia) cincta (Hutton, 1886).	x						
Cirsotrema zelebori (Dunker, 1866).				u - r			
Penion sp.							
Liratilia n.sp.							
Amalda (Baryspira) mucronata (Sowerby, 1830).			x				
Amalda (Baryspira) oraria (Olson, 1956).	x			u - c			
Phenatoma precursor Powell, 1942.	x		x				
Neothyris cf. *obtusa* Thom.					x	x	
Neothyris sp.		l - a		u - c			
Waltonia inconspicua (Sowerby).							
Notosaria nigricans							

WILKIES SHELLBED					
	apm23		apm24	**apm38**	apm56
	Kauarapaoa	Kauarapaoa	Kauarapaoa	**Wanganui**	Whangaehu
		GS4208			
Cosa trigonopsis (Hutton, 1885).		x			
Tucetona laticostata (Quoy & Gaimard, 1835).		x	l - r		
Modiolus areolatus (Gould, 1850).		x			
Atrina pectinata zelandica (Gray, 1835).					u - c (f)
Chlamys gemmulata (Reeve, 1853).	t - a	x	t - a	**t - c**	t - c (f)
Phialopecten thomsoni Marwick, 1965.	l - r (f)	x			
Anomia trigonopsis Hutton, 1877.					
Patro undatus Gray, 1850.					u - r (f)
Limaria orientalis (A. Adams & Reeve, 1850).					
Limatula maoria Finlay, 1926.		x	l - c		
Crassostrea ingens (Zittel, 1864).	t - a (f)		u - a (f)	**t - a**	
Ostrea chilensis lutaria (Hutton, 1873).			l - c	**t - c**	
Divaricella huttoniana (Vanatta, 1901).	l - c (f)	x			
Pteromyrtea dispar (Hutton, 1873).			l - c		
Mylitella finlayi (Marwick, 1924).					
Melliteryx parva (Deshayes, 1857).		x			
Purpurocardia purpurata (Deshayes, 1854).	l - a (f)	x		**l - c**	
Hamacuna nukumaruensis (Laws, 1940).					
Volupicuna laqueus (Finlay, 1926)					
Trachycardium (Ovicardium) rossi Marwick, 1944.					
Pratulum pulchellum (Gray, 1843).					u - r (f)
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972.)					
Maorimactra sp.					
Lutraria solida Hutton, 1873.			l - r		
Gari (Gobraeus) stangeri (Gray, 1843).					
Dosina n.sp.					
Bassina yatei (Gray, 1835).					
Tawera subsulcata (Suter, 1905).		x			
Dosinia (Asa) lambata (Gould, 1850).		x			
Dosinia (Phacosoma) subrosea (Gray, 1835).					
Dosinia (Raina) cf. *nukumaruensis* (Marwick, 1927).					
Dosinia sp.	?l - r?				
Eumarcia plana Marwick, 1927.		x	l - c		
Panopea zelandica (Quoy & Gaimard, 1835).					
Barnea (Anchomasa) similis (Gray, 1835).					
Emarginula striatula Quoy & Gaimard, 1834.					
Tugali sp.					
Crossea (Crosseola) waitotara (Laws, 1940).		x			
Zethalia zelandica (Hombron & Jacquinot, 1854).					
Argalista fluctuata (Hutton, 1883).		x			
Attenuata charassa (Finlay, 1924).		x			
Merelina sp.		x			
Pisinna seminsulcata (Hutton,1885).					
Maoricolpus roseus (Quoy & Gaimard, 1834)			l - c	**l - r**	
Stiraclopus propagada Laws, 1940.		x			
Stiracolpus huttoni huttoni (Cossman, 1912).		x			
Stiracolpus sp.					
Zeacolpus sp.					
Pelicaria n.sp. aff. *zelandiae* (Marshall & Murdoch, 1920).					
Crepidula radiata (Hutton, 1873).	l - c (f)				
Sigapatella novaezelandiae (Lesson, 1830).					
Zegalerus cf. crater Finlay, 1926.					
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).					
Polinices aff. *waipipiensis* (Marwick, 1924).					
Selia (Lyroselia) cincta (Hutton, 1886).					
Cirsotrema zelebori (Dunker, 1866).					
Penion sp.		x			
Liratilia n.sp.		x			
Amalda (Baryspira) mucronata (Sowerby, 1830).					
Amalda (Baryspira) oraria (Olson, 1956).	l - c (f)		l - c	**l - r**	
Phenatoma precursor Powell, 1942.					
Neothyris cf. *obtusa* Thom.					
Neothyris sp.	l - c (f)				
Waltonia inconspicua (Sowerby).	u - r				
Notosaria nigricans	u - c				

MANGAMAHU SHELLBED						
	apm9	apm15		apm25	apm41	apm57
	Okiwa	Paparangi	Paparangi	Kauarapaoa	Wanganui	Whangaehu
			GS 4210			
Chlamys gemmulata (Reeve, 1853).		u - c (f)	x	l - a	t - r	t - c
Phialopecten thomsoni Marwick, 1965.	u - r					
Patro undatus Gray, 1850.	t - c	u - c (f)	x			
Limatula maoria Finlay, 1926.	u - c					
Crassostrea ingens (Zittel, 1864).				u - a (f)		u - c
Ostrea chilensis lutaria (Hutton, 1873).				t - c	t - r	t - c
Divaricella huttoniana (Vanatta, 1901).		t - c	x			l - r
Pteromyrtea dispar (Hutton, 1873).	l - c		x			l - r
Purpurocardia purpurata (Deshayes, 1854).	t - a					
Maoricardium spatiosum (Hutton, 1873).	l - r (f)					
Trachycardium (Ovicardium) rossi Marwick, 1944.	l - r (f)					
Scalpomactra scalpellum (Reeve, 1854).			x			
Gari linoleata (Gray, 1835).			x			
Dosina zelandica Gray, 1835.						l - r
Dosinia (Kereia) greyi Zittel, 1864.						l - r
Eumarcia plana Marwick, 1927.						l - c
Panopea zelandica (Quoy & Gaimard, 1835).			x			
Maoricolpus roseus (Quoy & Gaimard, 1834)			x	l - c		u - r
Stiracolpus propagada Laws, 1940.			x			
Crepidula radiata (Hutton, 1873).	t - a					u - r
Sigapatella novaezelandiae (Lesson, 1830).	u - c					
Austrofusus taitae (Marwick, 1924).			x			
Penion sulcatus (Lamark, 1816).						u - r
Amalda (Baryspira) mucronata (Sowerby, 1830).			x			
Amalda (Baryspira) oraria (Olson, 1956).		u - c		l - c		t - c
Amalda sp.						l - c
Splendrillia kingmai Marwick, 1965.						u - r
Antalis nana (Hutton, 1873).						u - r
Neothyris sp.	t - a					
Fellaster zelandiae (Gray).						l - r
Pebbles						l - r

TIROTIRO SHELLBED								
		apm10	apm26	apm 27	apm28	apm29	apm42	apm58
	Okiwa	Okiwa	Kauarapaoa	Kauarapaoa	Kauarapaoa	Kauarapaoa	**Wanganui**	Whangaehu
	GS 4234							
Atrina pectinata zelandica (Gray, 1835).		u - c	u - c (f)	u - r		t - c (f)	**u - c**	t - c (f)
Chlamys gemmulata (Reeve, 1853).	x	t - r	l - c (f)	t - a	t - a	t - c	**t - a**	
Phialopecten thomsoni Marwick, 1965.							**u - r**	
Anomia trigonopsis Hutton, 1877.	x	t - c	l - c (f)		t - c			
Patro undatus Gray, 1850.			t - c (f)	u - r		t - c (f)	**u - c**	
Limatula maoria Finlay, 1926.							**l - r**	
Crassostrea ingens (Zittel, 1864).					u - c		**l - c**	
Ostrea chilensis lutaria (Hutton, 1873).	x						**l - c**	
Divaricella huttoniana (Vanatta, 1901).		l - r		l - c		l - r	**u - r**	
Mylitella finlayi (Marwick, 1924).				t - r				
Purpurocardia purpurata (Deshayes, 1854).							**u - c**	
Trachycardium (Ovicardium) rossi Marwick, 1944.		l - r						
Cyclomactra aff. *tristis* (Reeve, 1854).	x							
Zenatia acinaces (Quoy & Gaimard, 1835).			l - r (f)					
Dosina sp.							**u - r**	
Bassina yatei (Gray, 1835).							**l - r**	
Eumarcia plana Marwick, 1927.						l - c (f)		
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).	x							
Ruditapes sp.					l - r			
Caryocorbula zelandica (Quoy & Gaimard, 1835).				t - a	l - r			
Panopea wanganuica Powell, 1952.						u - r (f)	**u - c**	
Barnea (Anchomasa) similis (Gray, 1835).					l - r			
Myadora sp.						l - r		
Maoricolpus roseus (Quoy & Gaimard, 1834)		t - c	l - c (f)	l - r				
Zeacolpus vittatus (Hutton, 1873)					t - c			
Zeacolpus sp.							**u - r**	
Crepidula radiata (Hutton, 1873).	x	t - c		t - r	t - c	t - c		
Sigapatella novaezelandiae (Lesson, 1830).	x			l - c				
Penion sulcatus (Lamark, 1816).		u - r		u - r		l - r		
Xymene ambiguus (Phillipi, 1844).	x							
Amalda (Baryspira) mucronata (Sowerby, 1830).	x							
Amalda (Baryspira) oraria (Olson, 1956).		t - c					**u - c**	
Amalda sp.			l - c (f)	t - c	t - r			
Alcithoe sp.		u - r			u - r			
Comitas allani Powell, 1942.						l - r		
Splendrillia sp.		u - r						
Neothyris aff. *ovalis* (Hutton)	x							
Neothyris sp.			l - c (f)	u - r			**u - c**	
Fellaster zelandiae (Gray).				l - c	l - c		**l - c**	
Pebbles				l - a				

TE RAMA SHELLBED	Okiwa GS 4188	Okiwa GS 4189	apm11 Okiwa	apm17 Paparangi	apm43 Wanganui	
Nucula nitidula Adams, 1856.						
Atrina pectinata zelandica (Gray, 1835).				u - a		
Chlamys gemmulata (Reeve, 1853).	x	x	t - c	t - a	t - c	
Phialopecten thomsoni Marwick, 1965.	x	x	u - r	l - r		
Anomia trigonopsis Hutton, 1877.			t - c	u - r		
Patro undatus Gray, 1850.	x	x	u - c	t - c		
Lima waipipiensis Marshall & Murdoch, 1919.				l - r		
Limatula maoria Finlay, 1926.			l - r			
Crassostrea ingens (Zittel, 1864).						
Ostrea chilensis lutaria (Hutton, 1873).	x	x	u - c	u - c	t - c	
Divaricella huttoniana (Vanatta, 1901).					u - r	
Pteromyrtea dispar (Hutton, 1873).				l - r		
Mylitella finlayi (Marwick, 1924).						
Pleuromeris marshalli (Marwick, 1924).				l - r		
Purpurocardia purpurata (Deshayes, 1854).	x					
Talabrica senecta Powell, 1931.						
Cyclomactra aff. *tristis* (Reeve, 1854).		x				
Cyclomactra sp.				l - r		
Zenatia acinaces (Quoy & Gaimard, 1835).						
Gari linoleata (Gray, 1835).					u - c	
Dosina zelandica Gray, 1835.						
Dosina sp.				l - r		
Bassina yatei (Gray, 1835).					l - r	
Tawera subsulcata (Suter, 1905).	x					
Dosinia (Kereia) greyi Zittel, 1864.			l - c		u - c	
Eumarcia plana Marwick, 1927.					l - c	
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).						
Caryocorbula zelandica (Quoy & Gaimard, 1835).				l - c		
Panopea zelandica (Quoy & Gaimard, 1835).						
Calliostoma nukumaruense (Laws, 1930).				u - r		
Maoricolpus roseus (Quoy & Gaimard, 1834)	x			t - c		
Stiracolpus propagada Laws, 1940.		x				
Stiracolpus sp.					u - r	
Zeacolpus vittatus (Hutton, 1873)				t - c		
Pelicaria n.sp. aff. *acuminata* (Marwick, 1924).	x					
Crepidula radiata (Hutton, 1873).	x			t - c		
Sigapatella novaezelandiae (Lesson, 1830).				l - r		
Taniella planisutularis (Marwick, 1924).				u - c		
Penion sp.	x					
Poirieria zelandica (Quoy & Gaimard, 1833).	x					
Amalda (Baryspira) mucronata (Sowerby, 1830).	x					
Amalda (Baryspira) oraria (Olson, 1956).				t - c	u - c	
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).					u - r	
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).						
Amalda sp.			u - r			
Lamprodomina neozelanica (Hutton, 1885).	x			u - r		
Alcithoe (Lepromax) brevis Marwick, 1926.						
Alcithoe (Lepromax) aff. *brevis* Marwick, 1926.				u - r		
Clavatoma pulchra Powell, 1942.				u - r		
Aoteadrillia sp.						
Phenatoma precursor Powell, 1942.				l - r		
Tomopleura (Maoritomella) cf. *torquatella* (Marwick, 1931).				l - r		
Neothyris cf. *obtusa* Thom.		x				
Neothyris sp.				t - c		
Fellaster zelandiae (Gray).				l - r	l - c	
Pebbles			l - r	l - r		

TE RAMA SHELLBED				
	apm59		apm60	apm67
	Whangaehu	Creek Rd.	Creek Rd.	Turakina
		GS 4353		
Nucula nitidula Adams, 1856.	l - c			
Atrina pectinata zelandica (Gray, 1835).			u - c (f)	u - r (f)
Chlamys gemmulata (Reeve, 1853).	t - c	x		
Phialopecten thomsoni Marwick, 1965.				
Anomia trigonopsis Hutton, 1877.				l - r
Patro undatus Gray, 1850.	u - c (f)			
Lima waipipiensis Marshall & Murdoch, 1919.				
Limatula maoria Finlay, 1926.				
Crassostrea ingens (Zittel, 1864).	u - r (f)		t - c (f)	u - r (f)
Ostrea chilensis lutaria (Hutton, 1873).		x		
Divaricella huttoniana (Vanatta, 1901).		x		
Pteromyrtea dispar (Hutton, 1873).				
Mylitella finlayi (Marwick, 1924).	l - a			
Pleuromeris marshalli (Marwick, 1924).				
Purpurocardia purpurata (Deshayes, 1854).				
Talabrica senecta Powell, 1931.		x		
Cyclomactra aff. *tristis* (Reeve, 1854).				
Cyclomactra sp.				
Zenatia acinaces (Quoy & Gaimard, 1835).		x		l - r
Gari linoleata (Gray, 1835).				
Dosina zelandica Gray, 1835.		x		
Dosina sp.				
Bassina yatei (Gray, 1835).				
Tawera subsulcata (Suter, 1905).				
Dosinia (Kereia) greyi Zittel, 1864.		x		
Eumarcia plana Marwick, 1927.	l - r (f)			
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).		x		
Caryocorbula zelandica (Quoy & Gaimard, 1835).				
Panopea zelandica (Quoy & Gaimard, 1835).		x		
Calliostoma nukumaruense (Laws, 1930).				
Maoricolpus roseus (Quoy & Gaimard, 1834)		x		u - r
Stiracolpus propagada Laws, 1940.				
Stiracolpus sp.				
Zeacolpus vittatus (Hutton, 1873)				
Pelicaria n.sp. aff. *acuminata* (Marwick, 1924).				
Crepidula radiata (Hutton, 1873).		x		
Sigapatella novaezelandiae (Lesson, 1830).				
Taniella planisutularis (Marwick, 1924).				
Penion sp.				
Poirieria zelandica (Quoy & Gaimard, 1833).				
Amalda (Baryspira) mucronata (Sowerby, 1830).		x		
Amalda (Baryspira) oraria (Olson, 1956).				u - r
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).				
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).		x		
Amalda sp.	t - c			
Lamprodomina neozelanica (Hutton, 1885).				
Alcithoe (Lepromax) brevis Marwick, 1926.		x		
Alcithoe (Lepromax) aff. *brevis* Marwick, 1926.				
Clavatoma pulchra Powell, 1942.				
Aoteadrillia sp.		x		
Phenatoma precursor Powell, 1942.				
Tomopleura (Maoritomella) cf. *torquatella* (Marwick, 1931).				
Neothyris cf. *obtusa* Thom.				
Neothyris sp.				
Fellaster zelandiae (Gray).			l - c (f)	
Pebbles	l - r			

PARIHAUHAU SHELLBED								
	apm18	apm30	apm44			apm61	apm69	
	Paparangi	Kauarapaoa	Wanganui	Parihauhau	Creek Rd.	Creek Rd.	Turakina	Turakina
				GS 4205	GS 4362			GS 4349
Atrina pectinata zelandica (Gray, 1835).	u - a	u - c (f)	u - c	x				x
"Isognomon" zelandicus (Hutton in Suter, 1917).				x				
Chlamys gemmulata (Reeve, 1853).	t - a	l - a	t - c	x	x	t - c		x
Anomia trigonopsis Hutton, 1877.	t - c	t - c						
Patro undatus Gray, 1850.	u - c	t - c		x	x	u - a		
Crassostrea ingens (Zittel, 1864).		u - c (f)		x	x			x
Tiostrea chilensis lutaria (Hutton, 1873).	t - c		t - c			u - c		
Divaricella huttoniana (Vanatta, 1901).				x		l - c		
Miltha neozelanica Marshall & Murdoch, 1921.				x				
Pleuromeris marshalli (Marwick, 1924).						l - r		
Pratulum pulchellum (Gray, 1843).						u - r		
Dosina zelandica Gray, 1835.								x
Dosina sp.	l - r		t - r					
Dosinia (Kereia) aff. (n.sp?) *greyi* Zittel, 1864.	l - r							
Dosinia (Raina) nukumaruensis (Marwick, 1927).				x				
Dosinia sp.		l - r	l - r			l - r		
Eumarcia plana Marwick, 1927.				x				x
Emarginula haweraensis Powell, 1931.								x
Maoricolpus roseus (Quoy & Gaimard, 1834)	l - r	t - c		x		l - r		x
Stiracolpus sp.						l - r		
Zeacolpus vittatus (Hutton, 1873)	l - r							
Pelicaria sp.	u - r							
Crepidula radiata (Hutton, 1873).		l - c (f)		x		u - c		
Sigapatella novaezelandiae (Lesson, 1830).			l - r					x
Semicassis (Kahua) cf. *lilliei* (Fleming, 1943).								x
Aeneator aff. *attenuatus* Powell, 1927.								x
Penion aff. *haweraensis* (Powell, 1931).								x
Penion sulcatus (Lamark, 1816).						u - r (f)		
Penion sp.				x				
Amalda (Baryspira) mucronata (Sowerby, 1830).				x				
Amalda (Baryspira) oraria (Olson, 1956).	t - c		t - c			u - r		
Amalda (Baryspira) cf. *oraria* (Olson, 1956).							l - r	
Amalda (Gracilispira) cf. *novaezelandiae* (Sowerby, 1859).						t - c		
Amalda sp.						t - c		
Alcithoe (Lepromax) brevis Marwick, 1926.	u - r			x				x
Alcithoe (Lepromax) gatesi Marwick, 1926.						u - r		
Bathytoma (Micantapex) aff. *murdochi m.* (Finlay, 1930).				x				
Antalis nana (Hutton, 1873).						u - c		
Neothyris aff. *obtusa* Thom.				x				
Neothyris sp.	l - c	t - c						

SCHOOL SHELLBED						
	apm31		apm45	apm50	apm62	apm63
	Kauarapaoa	Kauarapaoa	**Wanganui**	Parihauhau	Creek Rd.	Whangaehu
		GS 4197				
Nielo sublaevis Marwick, 1926.			**u - r**			
Atrina pectinata zelandica (Gray, 1835).			**u - c**	t - c		
Panis zelandicus (Hutton in Suter, 1917).		x				
Chlamys gemmulata (Reeve, 1853).	t - a	x	**u - a**	t - a	l - c	u - c
Mesopeplum convexum (Quoy & Gaimard, 1835).		x				
Phialopecten thomsoni Marwick, 1965.	u - c					
Anomia trigonopsis Hutton, 1877.	l - c	x	**u - c**	l - c		
Patro undatus Gray, 1850.	l - c		**u - c**	u - c (f)	t - c	
Crassostrea ingens (Zittel, 1864).	u - a (f)	x	**u - a**	u - r		
Ostrea chilensis lutaria (Hutton, 1873).	u - c		**u - a**	u - c	t - c	
Divaricella huttoniana (Vanatta, 1901).	l - c (f)		**l - c**	u - c	l - c	
Pteromyrtea dispar (Hutton, 1873).			**l - c**	u - r	l - c	l - c
Pleuromeris hectori Powell, 1938.		x				
Purpurocardia purpurata (Deshayes, 1854).		x				
Dosina zelandica Gray, 1835.		x				
Tawera subsulcata (Suter, 1905).	l - r (f)					
Tawera aff. *subsulcata* (Suter, 1905).			**u - r**			
Dosinia (Kereia) greyi Zittel, 1864.				u - r		
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).				t - c (f)		
Dosinia sp.	l - c (f)		**l - c**			
Eumarcia plana Marwick, 1927.			**l - a**	l - c	l - c	l - a (f)
Myadora antipodium Smith, 1880.		x				
Myadora stephaniae Carter, 1972.	l - r					
Maoricolpus roseus (Quoy & Gaimard, 1834)				u - c		
Struthiolaria sp.						
Crepidula radiata (Hutton, 1873).	l - r			t - c		l - c
Sigapatella novaezelandiae (Lesson, 1830).					l - r	
Austrofusus sp.				u - r		
Penion sulcatus (Lamark, 1816).						u - r
Amalda (Baryspira) oraria (Olson, 1956).			**u - c**	t - c	l - c	
Amalda (Baryspira) cf. *oraria* (Olson, 1956).						
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).						u - r
Amalda sp.	l - c (f)					
Lamprodomina neozelanica (Hutton, 1885).				u - r		
Alcithoe (Leporomax) gatesi Marwick, 1926.			**u - r**			
Alcithoe sp.				u - r (f)		
Comitas allani Powell, 1942.				u - r		
Antalis ?pareorensis? (Pilsbry & Sharp, 1897).						
Neothyris sp.	l - c	x		u - c		
Notosaria nigricans (Sowerby).		x				
Fellaster zelandiae (Gray).	l - r			l - c (f)		l - c

SCHOOL SHELLBED			
	Turakina	West Rd.	Watershed Rd.
Nielo sublaevis Marwick, 1926.			
Atrina pectinata zelandica (Gray, 1835).			
Panis zelandicus (Hutton in Suter, 1917).			
Chlamys gemmulata (Reeve, 1853).	l - r (f)	t - r (f)	t - c (f)
Mesopeplum convexum (Quoy & Gaimard, 1835).			
Phialopecten thomsoni Marwick, 1965.			
Anomia trigonopsis Hutton, 1877.			
Patro undatus Gray, 1850.	l - r (f)		
Crassostrea ingens (Zittel, 1864).	u - r (f)		
Ostrea chilensis lutaria (Hutton, 1873).	t - r (f)		
Divaricella huttoniana (Vanatta, 1901).			
Pteromyrtea dispar (Hutton, 1873).			
Pleuromeris hectori Powell, 1938.			
Purpurocardia purpurata (Deshayes, 1854).			
Dosina zelandica Gray, 1835.			
Tawera subsulcata (Suter, 1905).			
Tawera aff. *subsulcata* (Suter, 1905).			
Dosinia (Kereia) greyi Zittel, 1864.	l - r (f)		
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).			
Dosinia sp.			t - r (f)?
Eumarcia plana Marwick, 1927.			
Myadora antipodium Smith, 1880.			
Myadora stephaniae Carter, 1972.			
Maoricolpus roseus (Quoy & Gaimard, 1834)			
Struthiolaria sp.	l - r (f)		
Crepidula radiata (Hutton, 1873).			
Sigapatella novaezelandiae (Lesson, 1830).			
Austrofusus sp.			
Penion sulcatus (Lamark, 1816).			
Amalda (Baryspira) oraria (Olson, 1956).			
Amalda (Baryspira) cf. *oraria* (Olson, 1956).	u - r (f)		
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).			
Amalda sp.			t - r (f)?
Lamprodomina neozelanica (Hutton, 1885).			
Alcithoe (Leporomax) gatesi Marwick, 1926.			
Alcithoe sp.			
Comitas allani Powell, 1942.			
Antalis ?pareorensis? (Pilsbry & Sharp, 1897).	u - r		
Neothyris sp.			
Notosaria nigricans (Sowerby).			
Fellaster zelandiae (Gray).			

HAUTAWA SHELLBED						
	apm12	apm19	apm32		apm46	
	Okiwa	Paparangi	Kauarapaoa	Kauarapaoa	Wanganui	Parihauhau
	(Kuranui)	(Kuranui)		GS 4198		GS 4201
Nielo sp.						
Arca cottoni Waghorn, 1926.						
Barbatia novaezealandiae (Smith, 1915).						x
Cosa trigonopsis (Hutton, 1885).			u - r			
Glycymeris waipipiensis (Marwick, 1923).						
Tucetona sp.	l - r					
Aulacomya ater maoriana (Iredale, 1915).					l - c	
Perna canaliculus (Gmelin, 1791).	u - r					
Modiolus areolatus (Gould, 1850).				x		x
Atrina pectinata zelandica (Gray, 1835).					u - c	x
Panis zelandicus (Hutton in Suter, 1917).						x
Chlamys gemmulata (Reeve, 1853).	t - c		t - a	x	t - a	x
Zygochlamys patagonica delicatula (Hutton, 1873).			u - r		l - r	
Mesopeplum convexum (Quoy & Gaimard, 1835).	t - c				l - r	
Phialopecten thomsoni Marwick, 1965.						
Phialopecten triphooki (Zittel, 1864).	t - c					
Anomia trigonopsis Hutton, 1877.			l - c		u - c	x
Patro undatus Gray, 1850.	t - c		l - c	x	t - c	x
Lima zealandica Sowerby, 1876.				x		
Limatula maoria Finlay, 1926.						
Crassostrea ingens (Zittel, 1864).	l - r					
Ostrea chilensis lutaria (Hutton, 1873).	t - a	t - c (f)	t - a		t - a	x
Divaricella huttoniana (Vanatta, 1901).			l - c	x		
Pteromyrtea dispar (Hutton, 1873).			l - r			
Felaniella (Zemysia) zelandica (Gray, 1835).						
Mylitella finlayi (Marwick, 1924).						
Kellia cycladiformis (Deshayes, 1839).						
Mysella larochei Powell, 1940.						
Cardita aoteana Finlay, 1929.						
Pleuromeris finlayi Powell, 1938.						
Pleuromeris hectori Powell, 1938.			t - c		t - c	x
Pleuromeris marshalli (Marwick, 1924).					u - r	
Pleuromeris zelandica (Deshayes, 1854).						
Purpurocardia purpurata (Deshayes, 1854).	t - r		t - c		t - a	
Talabrica senecta Powell, 1931.					u - c	
Trachycardium (Ovicardium) rossi Marwick, 1944.	l - r					
Pratulum pulchellum (Gray, 1843).					u - r	
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972).						
Maorimactra sp.					u - r	
Lutraria solida Hutton, 1873.						
Zenatia acinaces (Quoy & Gaimard, 1835).	l - r				u - r	
Serratina charlottae (Smith, 1885).						
Gari linoleata (Gray, 1835).					u - r	
Gari (Gobraeus) stangeri (Gray, 1843).						
Leptomya retiaria (Hutton, 1885).						
Dosina zelandica Gray, 1835.				x	u - r	
Marama murdochi Marwick, 1927.			u - r			
Bassina parva Marwick, 1927.						
Tawera subsulcata (Suter, 1905).						
Tawera sp.						
Dosinia (Kereia) greyi Zittel, 1864.						x
Dosinia (Phacosoma) subrosea (Gray, 1835).						
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).						
Notocallista (Stiracallista) multistriata (Sowerby, 1851).					u - r	
Eumarcia plana Marwick, 1927.			l - c			
Eumarcia (Atamarcia) benhami Marwick, 1927.					u - r	
Ruditapes largillierti (Phillipi, 1847).						
Caryocorbula zelandica (Quoy & Gaimard, 1835).						x
Panopea zelandica (Quoy & Gaimard, 1835).						
Barnea (Anchomasa) similis (Gray, 1835).						
Offadesma angasi (Crosse & Fischer, 1864).						
Myadora stephaniae Carter, 1972.						
Myadora striata (Quoy & Gaimard, 1835).						
Myadora sp.			t - r		u - r	
Haliotis sp.						

Emarginula striatula Quoy & Gaimard, 1834.					u - r	
Monodilepas monilifera (Hutton, 1873).						
Tugali elegans Gray, 1843.						
Tugali pliocenia Finlay, 1926.						
Tugali aff. *pliocenia* Finlay, 1926.						x
Patelloida corticata (Hutton, 1880).						
Cellana ornata (Dillwyn, 1817).						
Cellana strigilis (Hombron & Jacquinot, 1841).						
Crossea (Crosseola) waitotara (Laws, 1940).						
Dolicrossea vesca Finlay, 1926.						
Diloma sp.						
Micrelenchus sp.			u - r			
Zethalia coronata (Marwick, 1948).						
Calliostoma nukumaruense (Laws, 1930).						
Calliostoma aff. *nukumaruense* (Laws, 1930).						
Calliostoma sp.						
Astraea heliotropium (Martyn, 1784).						
Modelia granosa (Martyn, 1784).						
Maoricolpus roseus (Quoy & Gaimard, 1834)					u - a	x
Stiracolpus symmetricus (Hutton, 1873).					u - r	
Stiracolpus uttleyi uttleyi (Marwick, 1957).						
Stiracolpus wiltoni (Marwick, 1957).						
Stiracolpus n.sp.						x
Stiracolpus sp.			t - r			
Zeacolpus vittatus (Hutton, 1873)						
Pelicaria aff. *acuminata* (Marwick, 1924).						
Pelicaria convexa (Marwick, 1924).						
Pelicaria sp.						
Crepidula radiata (Hutton, 1873).	t - a	t - c (f)	l - c	x	l - c	
Sigapatella novaezelandiae (Lesson, 1830).	t - r		u - c		u - c	x
Zegalerus crater Finlay, 1926.						
Zegalerus cf. crater Finlay, 1926.				x		
Zegalerus tenuis (Gray, 1867).	t - r					
Trichosirius cavatocarinatus (Laws, 1940).						
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).						
Taniella planisutularis (Marwick, 1924).					u - r	
Ataxocerithium n.sp.						
Cirsotrema zelebori (Dunker, 1866).						
Hartungia typica Bronn, 1861.						
Aeneator sp.						
Austrofusus conoideus (Zittel, 1864).						
Austrofusus taitae (Marwick, 1924).						x
Austrofusus pagoda (Finlay, 1924).						
Austrofusus sp.						
Buccinulum cf. *linea linea* (Martyn, 1784).						
Buccinulum wairarapaensis Powell, 1938.						
Buccinulum sp.						
Cominella excoriata (Finlay, 1926).						
Cominella (Eucominia) aff. *hamiltoni* (Hutton, 1885).						
Penion haweraensis (Powell, 1931).						
Penion aff. *haweraensis* (Powell, 1931).						x
Penion sulcatus (Lamark, 1816).						
Penion sp.						x
Antizafra pisanopsis (Hutton, 1885).						
Xymene bonneti bonneti (Cossman, 1903).			u - c			
Coralliophila sertata (Hedley, 1903).						
Amalda (Baryspira) australis (Sowerby, 1830).						
Amalda (Baryspira) depressa (Sowerby, 1859).						
Amalda (Baryspira) mucronata (Sowerby, 1830).						
Amalda (Baryspira) oraria (Olson, 1956).					t - c	
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).						
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).						
Amalda (Gracilispira) cf. *novaezelandiae* (Sowerby, 1859).						
Amalda sp.			t - c			
Lamprodomina neozelanica (Hutton, 1885).					u - r	
Alcithoe arabica (Gmelin, 1791).						
Alcithoe (Leporemax) gatesi Marwick, 1926.						
Alcithoe (Leporemax) fusus fusus (Quoy & Gaimard, 1833).						
Duplicaria (Pervicacia) tristis (Deshayes, 1859).						
Antimelatoma buchanani buchanani (Hutton, 1873).						

Comitas allani Powell, 1942.						
Paracomitas protransenna (Marshall & Murdoch, 1923).						
Splendrillia aequistriata (Hutton, 1886).						
Splendrillia aff. *edita* Powell, 1942.						
Splendrillia sp.						
Aoteadrillia alpha (King, 1933).						
Bathytoma (Micantapex) murdochi m. (Finlay, 1930).						
Phenatoma rosea (Quoy & Gaimard, 1833).						
Antalis nana (Hutton, 1873).						
Fissidentalium zelandicum (Sowerby, 1860).						
Neothyris sp.	t - c		t - c	x	u - a	x
Waltonia inconspicua (Sowerby).				x	u - c	x
Notosaria nigricans					u - c	x
Magasella sanguinea (Leach).						x
Fellaster zelandiae (Gray).	l - r	l - r (f)	l - c			
Pebbles	t - a					

HAUTAWA SHELLBED						
				apm51	apm54	
	Parihauhau	Parihauhau	Parihauhau	Parihauhau	angawhero	angawhero
	GS 4206	GS 4225	GS 4204			GS 4357
Nielo sp.						
Arca cottoni Waghorn, 1926.						
Barbatia novaezealandiae (Smith, 1915).	x	x			u - r (f)	x
Cosa trigonopsis (Hutton, 1885).					l - c	
Glycymeris waipipiensis (Marwick, 1923).						
Tucetona sp.						
Aulacomya ater maoriana (Iredale, 1915).						
Perna canaliculus (Gmelin, 1791).						
Modiolus areolatus (Gould, 1850).		x				
Atrina pectinata zelandica (Gray, 1835).						
Panis zelandicus (Hutton in Suter, 1917).					u - r	
Chlamys gemmulata (Reeve, 1853).	x	x	x		t - a	x
Zygochlamys patagonica delicatula (Hutton, 1873).			x		l - r	
Mesopeplum convexum (Quoy & Gaimard, 1835).						x
Phialopecten thomsoni Marwick, 1965.						
Phialopecten triphooki (Zittel, 1864).	x					
Anomia trigonopsis Hutton, 1877.		x				
Patro undatus Gray, 1850.			x			
Lima zealandica Sowerby, 1876.	x					
Limatula maoria Finlay, 1926.						
Crassostrea ingens (Zittel, 1864).						
Ostrea chilensis lutaria (Hutton, 1873).	x	x			t - c	
Divaricella huttoniana (Vanatta, 1901).	x					
Pteromyrtea dispar (Hutton, 1873).						
Felaniella (Zemysia) zelandica (Gray, 1835).						
Mylitella finlayi (Marwick, 1924).						
Kellia cycladiformis (Deshayes, 1839).			x			
Mysella larochei Powell, 1940.						
Cardita aoteana Finlay, 1929.						
Pleuromeris finlayi Powell, 1938.						
Pleuromeris hectori Powell, 1938.	x	x	x			
Pleuromeris marshalli (Marwick, 1924).						
Pleuromeris zelandica (Deshayes, 1854).	x					
Purpurocardia purpurata (Deshayes, 1854).	x	x	x		t - a	x
Talabrica senecta Powell, 1931.		x	x			x
Trachycardium (Ovicardium) rossi Marwick, 1944.						
Pratulum pulchellum (Gray, 1843).					u - c	
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972).		x				
Maorimactra sp.						
Lutraria solida Hutton, 1873.						
Zenatia acinaces (Quoy & Gaimard, 1835).	x					
Serratina charlottae (Smith, 1885).						
Gari linoleata (Gray, 1835).						
Gari (Gobraeus) stangeri (Gray, 1843).						
Leptomya retiaria (Hutton, 1885).						
Dosina zelandica Gray, 1835.						
Marama murdochi Marwick, 1927.						
Bassina parva Marwick, 1927.						
Tawera subsulcata (Suter, 1905).						x
Tawera sp.			x			
Dosinia (Kereia) greyi Zittel, 1864.	x					
Dosinia (Phacosoma) subrosea (Gray, 1835).						
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).						x
Notocallista (Stiracallista) multistriata (Sowerby, 1851).						
Eumarcia plana Marwick, 1927.						
Eumarcia (Atamarcia) benhami Marwick, 1927.						
Ruditapes largillierti (Phillipi, 1847).	x					x
Caryocorbula zelandica (Quoy & Gaimard, 1835).						
Panopea zelandica (Quoy & Gaimard, 1835).						
Barnea (Anchomasa) similis (Gray, 1835).	x					x
Offadesma angasi (Crosse & Fischer, 1864).						
Myadora stephaniae Carter, 1972.						
Myadora striata (Quoy & Gaimard, 1835).					l - r	x
Myadora sp.						
Haliotis sp.						

Emarginula striatula Quoy & Gaimard, 1834.	x					
Monodilepas monilifera (Hutton, 1873).						
Tugali elegans Gray, 1843.						
Tugali pliocenia Finlay, 1926.					l - r	
Tugali aff. *pliocenia* Finlay, 1926.	x					
Patelloida corticata (Hutton, 1880).						
Cellana ornata (Dillwyn, 1817).						
Cellana strigilis (Hombron & Jacquinot, 1841).						
Crossea (Crosseola) waitotara (Laws, 1940).					l - r	
Dolicrossea vesca Finlay, 1926.						
Diloma sp.						
Micrelenchus sp.						
Zethalia coronata (Marwick, 1948).						
Calliostoma nukumaruense (Laws, 1930).					u - r	
Calliostoma aff. *nukumaruense* (Laws, 1930).						
Calliostoma sp.						
Astraea heliotropium (Martyn, 1784).			x			
Modelia granosa (Martyn, 1784).						
Maoricolpus roseus (Quoy & Gaimard, 1834)	x	x	x		t - c	
Stiracolpus symmetricus (Hutton, 1873).	x	x				x
Stiracolpus uttleyi uttleyi (Marwick, 1957).						
Stiracolpus wiltoni (Marwick, 1957).						
Stiracolpus n.sp.	x	x	x			
Stiracolpus sp.						
Zeacolpus vittatus (Hutton, 1873)						
Pelicaria aff. *acuminata* (Marwick, 1924).	x		x			
Pelicaria convexa (Marwick, 1924).						
Pelicaria sp.					u - c	
Crepidula radiata (Hutton, 1873).		x			t - c	
Sigapatella novaezelandiae (Lesson, 1830).					t - r	x
Zegalerus crater Finlay, 1926.	x					
Zegalerus cf. crater Finlay, 1926.						
Zegalerus tenuis (Gray, 1867).						
Trichosirius cavatocarinatus (Laws, 1940).						
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).	x		x			
Taniella planisutularis (Marwick, 1924).					u - c	
Ataxocerithium n.sp.	x		x			
Cirsotrema zelebori (Dunker, 1866).						
Hartungia typica Bronn, 1861.						
Aeneator sp.	x				u - c	
Austrofusus conoideus (Zittel, 1864).						
Austrofusus taitae (Marwick, 1924).	x					
Austrofusus pagoda (Finlay, 1924).						
Austrofusus sp.						
Buccinulum cf. *linea linea* (Martyn, 1784).						
Buccinulum wairarapaensis Powell, 1938.						
Buccinulum sp.						
Cominella excoriata (Finlay, 1926).						
Cominella (Eucominia) aff. *hamiltoni* (Hutton, 1885).						
Penion haweraensis (Powell, 1931).						x
Penion aff. *haweraensis* (Powell, 1931).						
Penion sulcatus (Lamark, 1816).					l - r	
Penion sp.						
Antizafra pisanopsis (Hutton, 1885).	x					
Xymene bonneti bonneti (Cossman, 1903).						
Coralliophila sertata (Hedley, 1903).						
Amalda (Baryspira) australis (Sowerby, 1830).						
Amalda (Baryspira) depressa (Sowerby, 1859).					u - r	
Amalda (Baryspira) mucronata (Sowerby, 1830).						
Amalda (Baryspira) oraria (Olson, 1956).						
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).						
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).	x					
Amalda (Gracilispira) cf. *novaezelandiae* (Sowerby, 1859).			x			
Amalda sp.						
Lamprodomina neozelanica (Hutton, 1885).						
Alcithoe arabica (Gmelin, 1791).						
Alcithoe (Leporemax) gatesi Marwick, 1926.						
Alcithoe (Leporemax) fusus fusus (Quoy & Gaimard, 1833).						
Duplicaria (Pervicacia) tristis (Deshayes, 1859).						
Antimelatoma buchanani buchanani (Hutton, 1873).						x

Comitas allani Powell, 1942.	x					
Paracomitas protransenna (Marshall & Murdoch, 1923).						
Splendrillia aequistriata (Hutton, 1886).						
Splendrillia aff. *edita* Powell, 1942.		x				
Splendrillia sp.						
Aoteadrillia alpha (King, 1933).						
Bathytoma (Micantapex) murdochi m. (Finlay, 1930).						
Phenatoma rosea (Quoy & Gaimard, 1833).						
Antalis nana (Hutton, 1873).	x					
Fissidentalium zelandicum (Sowerby, 1860).						
Neothyris sp.	x	x	x	t - c	u - r	x
Waltonia inconspicua (Sowerby).	x	x		u - r		
Notosaria nigricans	x			t - a		x
Magasella sanguinea (Leach).				u - c		
Fellaster zelandiae (Gray).						
Pebbles						

HAUTAWA SHELLBED						
	apm64	apm65			apm70	
	Whangaehu	Whangaehu	Whangaehu	Creek Rd.	West Rd.	West Rd.
			GS 4355	GS 4369		GS 3096
Nielo sp.						
Arca cottoni Waghorn, 1926.						
Barbatia novaezealandiae (Smith, 1915).			x			
Cosa trigonopsis (Hutton, 1885).						
Glycymeris waipipiensis (Marwick, 1923).						
Tucetona sp.						
Aulacomya ater maoriana (Iredale, 1915).						x
Perna canaliculus (Gmelin, 1791).		u - r				
Modiolus areolatus (Gould, 1850).						
Atrina pectinata zelandica (Gray, 1835).			x			
Panis zelandicus (Hutton in Suter, 1917).		u - r	x			x
Chlamys gemmulata (Reeve, 1853).	l - c		x	x		x
Zygochlamys patagonica delicatula (Hutton, 1873).	l - c		x		l - r	x
Mesopeplum convexum (Quoy & Gaimard, 1835).						x
Phialopecten thomsoni Marwick, 1965.						
Phialopecten triphooki (Zittel, 1864).				x		x
Anomia trigonopsis Hutton, 1877.	l - c					
Patro undatus Gray, 1850.			x			x
Lima zealandica Sowerby, 1876.						
Limatula maoria Finlay, 1926.	l - r		x?			
Crassostrea ingens (Zittel, 1864).						
Ostrea chilensis lutaria (Hutton, 1873).	t - c		x			
Divaricella huttoniana (Vanatta, 1901).						
Pteromyrtea dispar (Hutton, 1873).	l - r					
Felaniella (Zemysia) zelandica (Gray, 1835).						x
Mylitella finlayi (Marwick, 1924).	l - r					
Kellia cycladiformis (Deshayes, 1839).						
Mysella larochei Powell, 1940.						
Cardita aoteana Finlay, 1929.						
Pleuromeris finlayi Powell, 1938.						
Pleuromeris hectori Powell, 1938.	l - c					x
Pleuromeris marshalli (Marwick, 1924).	t - r					
Pleuromeris zelandica (Deshayes, 1854).						
Purpurocardia purpurata (Deshayes, 1854).	l - c		x			x
Talabrica senecta Powell, 1931.	t - c		x			x
Trachycardium (Ovicardium) rossi Marwick, 1944.						
Pratulum pulchellum (Gray, 1843).						
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972).	l - r					
Maorimactra sp.						
Lutraria solida Hutton, 1873.						x
Zenatia acinaces (Quoy & Gaimard, 1835).			x			
Serratina charlottae (Smith, 1885).						
Gari linoleata (Gray, 1835).						
Gari (Gobraeus) stangeri (Gray, 1843).						
Leptomya retiaria (Hutton, 1885).						x
Dosina zelandica Gray, 1835.						
Marama murdochi Marwick, 1927.						
Bassina parva Marwick, 1927.						
Tawera subsulcata (Suter, 1905).	l - r					
Tawera sp.						
Dosinia (Kereia) greyi Zittel, 1864.						
Dosinia (Phacosoma) subrosea (Gray, 1835).						
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).						
Notocallista (Stiracallista) multistriata (Sowerby, 1851).						x
Eumarcia plana Marwick, 1927.			x			
Eumarcia (Atamarcia) benhami Marwick, 1927.						
Ruditapes largillierti (Phillipi, 1847).						
Caryocorbula zelandica (Quoy & Gaimard, 1835).						x
Panopea zelandica (Quoy & Gaimard, 1835).			x			
Barnea (Anchomasa) similis (Gray, 1835).						
Offadesma angasi (Crosse & Fischer, 1864).						
Myadora stephaniae Carter, 1972.						
Myadora striata (Quoy & Gaimard, 1835).						
Myadora sp.	l - r					
Haliotis sp.						

Emarginula striatula Quoy & Gaimard, 1834.					
Monodilepas monilifera (Hutton, 1873).			x		
Tugali elegans Gray, 1843.					
Tugali pliocenia Finlay, 1926.					
Tugali aff. *pliocenia* Finlay, 1926.					
Patelloida corticata (Hutton, 1880).					
Cellana ornata (Dillwyn, 1817).					
Cellana strigilis (Hombron & Jacquinot, 1841).					
Crossea (Crosseola) waitotara (Laws, 1940).					
Dolicrossea vesca Finlay, 1926.					
Diloma sp.					
Micrelenchus sp.	l - r				
Zethalia coronata (Marwick, 1948).					
Calliostoma nukumaruense (Laws, 1930).	l - r				
Calliostoma aff. *nukumaruense* (Laws, 1930).					
Calliostoma sp.	l - r				
Astraea heliotropium (Martyn, 1784).					
Modelia granosa (Martyn, 1784).					
Maoricolpus roseus (Quoy & Gaimard, 1834)	l - r		x		x
Stiracolpus symmetricus (Hutton, 1873).			x		
Stiracolpus uttleyi uttleyi (Marwick, 1957).					
Stiracolpus wiltoni (Marwick, 1957).					
Stiracolpus n.sp.					x
Stiracolpus sp.	t - c				
Zeacolpus vittatus (Hutton, 1873)					
Pelicaria aff. *acuminata* (Marwick, 1924).					x
Pelicaria convexa (Marwick, 1924).					
Pelicaria sp.	l - c				
Crepidula radiata (Hutton, 1873).	t - a		x		
Sigapatella novaezelandiae (Lesson, 1830).	t - c				x
Zegalerus crater Finlay, 1926.					x
Zegalerus cf. crater Finlay, 1926.					
Zegalerus tenuis (Gray, 1867).					
Trichosirius cavatocarinatus (Laws, 1940).					
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).			x		x
Taniella planisutularis (Marwick, 1924).	l - r				x
Ataxocerithium n.sp.					
Cirsotrema zelebori (Dunker, 1866).			x		
Hartungia typica Bronn, 1861.					
Aeneator sp.					
Austrofusus conoideus (Zittel, 1864).					x
Austrofusus taitae (Marwick, 1924).					
Austrofusus pagoda (Finlay, 1924).					
Austrofusus sp.					
Buccinulum cf. *linea linea* (Martyn, 1784).					
Buccinulum wairarapaensis Powell, 1938.					
Buccinulum sp.					x
Cominella excoriata (Finlay, 1926).	l - r				
Cominella (Eucominia) aff. *hamiltoni* (Hutton, 1885).					x
Penion haweraensis (Powell, 1931).					
Penion aff. *haweraensis* (Powell, 1931).					
Penion sulcatus (Lamark, 1816).					
Penion sp.					
Antizafra pisanopsis (Hutton, 1885).					
Xymene bonneti bonneti (Cossman, 1903).	l - r				
Coralliophila sertata (Hedley, 1903).					
Amalda (Baryspira) australis (Sowerby, 1830).					
Amalda (Baryspira) depressa (Sowerby, 1859).					
Amalda (Baryspira) mucronata (Sowerby, 1830).					
Amalda (Baryspira) oraria (Olson, 1956).	t - c				
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).					
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).	l - r				
Amalda (Gracilispira) cf. *novaezelandiae* (Sowerby, 1859).			x		
Amalda sp.	l - r				
Lamprodomina neozelanica (Hutton, 1885).					
Alcithoe arabica (Gmelin, 1791).	l - r				
Alcithoe (Leporemax) gatesi Marwick, 1926.					
Alcithoe (Leporemax) fusus fusus (Quoy & Gaimard, 1833).					
Duplicaria (Pervicacia) tristis (Deshayes, 1859).					
Antimelatoma buchanani buchanani (Hutton, 1873).					

Comitas allani Powell, 1942.					
Paracomitas protransenna (Marshall & Murdoch, 1923).					
Splendrillia aequistriata (Hutton, 1886).					x
Splendrillia aff. *edita* Powell, 1942.					
Splendrillia sp.					
Aoteadrillia alpha (King, 1933).					
Bathytoma (Micantapex) murdochi m. (Finlay, 1930).					
Phenatoma rosea (Quoy & Gaimard, 1833).					x
Antalis nana (Hutton, 1873).					x
Fissidentalium zelandicum (Sowerby, 1860).					
Neothyris sp.	t - a		x		
Waltonia inconspicua (Sowerby).			x	x	x
Notosaria nigricans	t - a	t - c	x	x	x
Magasella sanguinea (Leach).	l - r				
Fellaster zelandiae (Gray).	l - r				
Pebbles					

HAUTAWA SHELLBED				
		apm71		apm72
	West Rd. Naish '96	Watershed Rd.	Rangitikei Naish	Komako Carter' 72
Nielo sp.	x			
Arca cottoni Waghorn, 1926.				x (t)
Barbatia novaezealandiae (Smith, 1915).				
Cosa trignopsis (Hutton, 1885).		1 - r		
Glycymeris waipipiensis (Marwick, 1923).				x
Tucetona sp.				
Aulacomya ater maoriana (Iredale, 1915).	x	1 - c		x (l)
Perna canaliculus (Gmelin, 1791).		1 - r		
Modilus areolatus (Gould, 1850).	x			x
Atrina pectinata zelandica (Gray, 1835).			x	
Panis zelandicus (Hutton in Suter, 1917).				x
Chlamys gemmulata (Reeve, 1853).				x
Zygochlamys patagonica delicatula (Hutton, 1873).	x	1 - c	x	x (u)
Mesopeplum convexum (Quoy & Gaimard, 1835).				x
Phialopecten thomsoni Marwick, 1965.				x (l)
Phialopecten triphooki (Zittel, 1864).				x (u)
Anomia trignopsis Hutton, 1877.	x	1 - c	x	x
Patro undatus Gray, 1850.	x	1 - c	x	
Lima zealandica Sowerby, 1876.				
Limatula maoria Finlay, 1926.				x
Crassostrea ingens (Zittel, 1864).		1 - r		x (l)
Ostrea chilensis lutaria (Hutton, 1873).	x	1 - c	x	
Divaricella huttoniana (Vanatta, 1901).				x
Pteromyrtea dispar (Hutton, 1873).	x			
Felaniella (Zemysia) zelandica (Gray, 1835).				
Mylitella finlayi (Marwick, 1924).				
Kellia cycladoformis (Deshayes, 1839).				
Mysella larochei Powell, 1940.				x
Cardita aoteana Finlay, 1929.	x		x	
Pleuromeris finlayi Powell, 1938.				x
Pleuromeris hectori Powell, 1938.		1 - c		
Pleuromeris marshalli (Marwick, 1924).	x		x	
Pleuromeris zelandica (Deshayes, 1854).				
Purpurocardia purpurata (Deshayes, 1854).	x	1 - a		x
Talabrica senecta Powell, 1931.	x	1 - r		x
Trachycardium (Ovicardium) rossi Marwick, 1944.				
Pratulum pulchellum (Gray, 1843).			x	
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972).		1 - r		
Maorimactra sp.				
Lutraria solida Hutton, 1873.				
Zenatia acinaces (Quoy & Gaimard, 1835).	x			
Serratina charlottae (Smith, 1885).		u - r		
Gari linoleata (Gray, 1835).				x
Gari (Gobraeus) stangeri (Gray, 1843).				x
Leptomya retiaria (Hutton, 1885).				
Dosina zelandica Gray, 1835.	x	1 - r	x	
Marama murdochi Marwick, 1927.				
Bassina parva Marwick, 1927.				x
Tawera subsulcata (Suter, 1905).				x (l)
Tawera sp.				
Dosinia (Kereia) greyi Zittel, 1864.				
Dosinia (Phacosoma) subrosea (Gray, 1835).				x
Dosinia (Phacosoma) aff. *subrosea* (Gray, 1835).				
Notocallista (Stiracallista) multistriata (Sowerby, 1851).				x
Eumarcia plana Marwick, 1927.				
Eumarcia (Atamarcia) benhami Marwick, 1927.				x
Ruditapes largillierti (Phillipi, 1847).				
Caryocorbula zelandica (Quoy & Gaimard, 1835).			x	
Panopea zelandica (Quoy & Gaimard, 1835).				x
Barnea (Anchomasa) similis (Gray, 1835).				
Offadesma angasi (Crosse & Fischer, 1864).				x
Myadora stephaniae Carter, 1972.				x
Myadora striata (Quoy & Gaimard, 1835).				
Myadora sp.				
Haliotis sp.				x

Emarginula striatula Quoy & Gaimard, 1834.				x
Monodilepas monilifera (Hutton, 1873).				
Tugali elegans Gray, 1843.				x
Tugali pliocenia Finlay, 1926.		u - r		
Tugali aff. *pliocenia* Finlay, 1926.				
Patelloida cornicata (Hutton, 1880).				x
Cellana ornata (Dillwyn, 1817).				x
Cellana strigilis (Hombron & Jacquinot, 1841).				x
Crossea (Crosseola) waitotara (Laws, 1940).				
Dolicrossea vesca Finlay, 1926.			x	
Diloma sp.				x
Micrelenchus sp.				x
Zethalia coronata (Marwick, 1948).				x (l)
Calliostoma nukumaruense (Laws, 1930).				
Calliostoma aff. *nukumaruense* (Laws, 1930).	x		x	
Calliostoma sp.				
Astraea heliotropium (Martyn, 1784).				
Modelia granosa (Martyn, 1784).				x
Maoricolpus roseus (Quoy & Gaimard, 1834)		l - c		x
Stiracolpus symmetricus (Hutton, 1873).				
Stiracolpus uttleyi uttleyi (Marwick, 1957).			x	
Stiracolpus wiltoni (Marwick, 1957).				x
Stiracolpus n.sp.				
Stiracolpus sp.		l - r		
Zeacolpus vittatus (Hutton, 1873)	x	l - c		
Pelicaria aff. *acuminata* (Marwick, 1924).				
Pelicaria convexa (Marwick, 1924).	x			x
Pelicaria sp.				
Crepidula radiata (Hutton, 1873).			x	
Sigapatella novaezelandiae (Lesson, 1830).		l - r	x	x
Zegalerus crater Finlay, 1926.				
Zegalerus cf. crater Finlay, 1926.				
Zegalerus tenuis (Gray, 1867).				x
Trichosirius cavatocarinatus (Laws, 1940).			x	
Tanea aff. *zelandica* (Quoy & Gaimard, 1832).				
Taniella planisutularis (Marwick, 1924).		t - r		x
Ataxocerithium n.sp.				
Cirsotrema zelebori (Dunker, 1866).				
Hartungia typica Bronn, 1861.				x (t)
Aeneator sp.				
Austrofusus conoideus (Zittel, 1864).				
Austrofusus tatiae (Marwick, 1924).				
Austrofusus pagoda (Finlay, 1924).				x
Austrofusus sp.	x			
Buccinulum cf. *linea linea* (Martyn, 1784).		l - r		
Buccinulum wairarapaensis Powell, 1938.				x
Buccinulum sp.				
Cominella excoriata (Finlay, 1926).				
Cominella (Eucominia) aff. *hamiltoni* (Hutton, 1885).				
Penion haweraensis (Powell, 1931).				
Penion aff. *haweraensis* (Powell, 1931).				
Penion sulcatus (Lamark, 1816).	x		x	
Penion sp.				
Antizafra pisanopsis (Hutton, 1885).				
Xymene bonneti bonneti (Cossman, 1903).		l - r		
Coralliophila sertata (Hedley, 1903).				x
Amalda (Baryspira) australis (Sowerby, 1830).				x
Amalda (Baryspira) depressa (Sowerby, 1859).				
Amalda (Baryspira) mucronata (Sowerby, 1830).			x	x
Amalda (Baryspira) oraria (Olson, 1956).		t - c		
Amalda (Gracilispira) novaezelandiae (Sowerby, 1859).	x	l - r	x	
Amalda (Gracilispira) aff. *novaezelandiae* (Sowerby, 1859).				
Amalda (Gracilispira) cf. *novaezelandiae* (Sowerby, 1859).				
Amalda sp.			x	
Lamprodomina neozelandica (Hutton, 1885).				x (t)
Alcithoe arabica (Gmelin, 1791).		u - r		
Alcithoe (Lepromax) gatesi Marwick, 1926.			x	
Alcithoe (Lepromax) fusus fusus (Quoy & Gaimard, 1833).				x
Duplicaria (Pervicacia) tristis (Deshayes, 1859).				x
Antimelatoma buchanani buchanani (Hutton, 1873).				

Comitas allani Powell, 1942.				
Paracomitas protransenna (Marshall & Murdoch, 1923).			x	
Splendrillia aequistriata (Hutton, 1886).		u - c		
Splendrill ia aff. *edita* Powell, 1942.				
Splendrillia sp.	x			
Aoteadrillia alpha (King, 1933).				x
Bathytoma (Micantapex) murdochi m. (Finlay, 1930).		u - r		
Phenatoma rosea (Quoy & Gaimard, 1833).				
Antalis nana (Hutton, 1873).		u - c	x	
Fissidentalium zelandicum (Sowerby, 1860).				x
Neothyris sp.	x			
Waltonia inconspicua (Sowerby).				
Notosaria nigricans				
Magasella sanguinea (Leach).				
Fellaster zelandiae				
Pebbles				

MISCELLANEOUS SITES						
	apm13	apm16		apm33	apm34	apm37
	Paparngi	Paparngi	Kauarap.	Kauarap.	Wnganui	Wnganui
			GS 4196	Tuha		Makokako
Amygdalum striatum (Hutton, 1873).					l - r	
Atrina pectinata zelandica (Gray, 1835).						t - r
Chlamys gemmulata (Reeve, 1853).		t - r		t - a (f)		l - r
Phialopecten marwicki (Beu, 1970).						
Anomia trigonopsis Hutton, 1877.		u - c				
Patro undatus Gray, 1850.		u - a		t - a (f)	l - r	
Limatula maoria Finlay, 1926.		l - r				
Crassostrea ingens (Zittel, 1864).						
Ostrea chilensis lutaria (Hutton, 1873).						
Divaricella huttoniana (Vanatta, 1901).			x		l - r	l - r
Pteromyrtea dispar (Hutton, 1873).						
Purpurocardia purpurata (Deshayes, 1854).				t - c (f)		
Maoricardium spatiosum (Hutton, 1873).						
Pratulum sp.	t - c				u - r	
Cyclomactra sp.		t - c				
Zenatia acinaces (Quoy & Gaimard, 1835).				t - r (f)		
Gari linoleata (Gray, 1835).						
Dosina zelandica Gray, 1835.						
Dosina sp.		l - r				
Bassina yatei (Gray, 1835).			x			
Tawera subsulcata (Suter, 1905).				t - c (f)		
Eumarcia plana Marwick, 1927.						l - r
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).			x			
Caryocorbula zelandica (Quoy & Gaimard, 1835).						
Barnea (Anchomasa) similis (Gray, 1835).	t - c					
Myadora kaiiwiensis Powell, 1931.						
Maoricolpus roseus (Quoy & Gaimard, 1834)						
Stiracolpus sp.						
Pelicaria n.sp. aff. zelandiae (Marshall & Murdoch, 1920).						
Taniella planisutularis (Marwick, 1924).						
Polinices waipipiensis (Marwick, 1924).					l - r	
Semicassis (Kahua) fibrata (M & M, 1920).					x	
Cirsotrema zelebori (Dunker, 1866).						
Austrofusus pagoda (Finlay, 1924).						
Xymene "drewi" (Hutton)		u - r				
Amalda (Baryspira) oraria (Olson, 1956).		t - c				
Amalda novaezelandiae (Sowerby, 1859).						
Amalda (Gracilispira) cf. *rimuensis* (Olson, 1956).		t - r				
Amalda sp.					l - r	
Alcithoe haweraensis Marwick, 1926.						
Alcithoe cf. *whakinoensis* Marwick, 1926.					u - r	
Splendrillia aequistriata (Hutton, 1886).						
Tomopleura (Maoritomella) cf. *robusta* (Powell, 1942).						
Fissidentalium zelandicum (Sowerby, 1860).						
Neothyris sp.		u - c				
Magasella sanguinea (Leach).						
Fellaster zelandiae (Gray).						

MISCELLANEOUS SITES					
	apm39	apm40		apm48	apm49
	Wanganui	Wanganui	Wanganui	Wanganui	Wanganui
	Cable zst	Te Rimu	GS 4214	Piripiri	
Amygdalum striatum (Hutton, 1873).					
Atrina pectinata zelandica (Gray, 1835).	t - r			t - c	
Chlamys gemmulata (Reeve, 1853).	t - r	l - r		t - c	t - c
Phialopecten marwicki (Beu, 1970).					
Anomia trigonopsis Hutton, 1877.					
Patro undatus Gray, 1850.					
Limatula maoria Finlay, 1926.					
Crassostrea ingens (Zittel, 1864).					
Ostrea chilensis lutaria (Hutton, 1873).	u - r	l - r		l - c	t - c
Divaricella huttoniana (Vanatta, 1901).		t - r	x		
Pteromyrtea dispar (Hutton, 1873).		t - r	x		
Purpurocardia purpurata (Deshayes, 1854).				l - c	
Maoricardium spatiosum (Hutton, 1873).					
Pratulum sp.					
Cyclomactra sp.					
Zenatia acinaces (Quoy & Gaimard, 1835).				l - r	
Gari linoleata (Gray, 1835).		t - r	x		
Dosina zelandica Gray, 1835.					
Dosina sp.					
Bassina yatei (Gray, 1835).		t - r	x	t - c	
Tawera subsulcata (Suter, 1905).					
Eumarcia plana Marwick, 1927.					
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).		t - r	x		
Caryocorbula zelandica (Quoy & Gaimard, 1835).				t - c	
Barnea (Anchomasa) similis (Gray, 1835).					
Myadora kaiiwiensis Powell, 1931.				l - r	
Maoricolpus roseus (Quoy & Gaimard, 1834)				u - c	
Stiracolpus sp.					
Pelicaria n.sp. aff. zelandiae (Marshall & Murdoch, 1920).					
Taniella planisutularis (Marwick, 1924).					
Polinices waipipiensis (Marwick, 1924).					
Semicassis (Kahua) fibrata (M & M, 1920).					
Cirsotrema zelebori (Dunker, 1866).				u - r	
Austrofusus pagoda (Finlay, 1924).					
Xymene "drewi" (Hutton)					
Amalda (Baryspira) oraria (Olson, 1956).					
Amalda novaezelandiae (Sowerby, 1859).	t - r		x		
Amalda (Gracilispira) cf. *rimuensis* (Olson, 1956).					
Amalda sp.					
Alcithoe haweraensis Marwick, 1926.					
Alcithoe cf. *whakinoensis* Marwick, 1926.					
Splendrillia aequistriata (Hutton, 1886).					
Tomopleura (Maoritomella) cf. *robusta* (Powell, 1942).					
Fissidentalium zelandicum (Sowerby, 1860).					
Neothyris sp.				t - c	
Magasella sanguinea (Leach).				u - r	
Fellaster zelandiae (Gray).					

MISCELLANEOUS SITES					
	apm52	apm53	apm66		
	Parihauhau	angawhero	Whangaehu	Saddle Rd	Saddle Rd
	Upokonui	Atene	Tuha zst	Lwr Lst	Upr Lst
Amygdalum striatum (Hutton, 1873).					
Atrina pectinata zelandica (Gray, 1835).					
Chlamys gemmulata (Reeve, 1853).					
Phialopecten marwicki (Beu, 1970).				t - r	t - c
Anomia trigonopsis Hutton, 1877.					
Patro undatus Gray, 1850.					
Limatula maoria Finlay, 1926.					
Crassostrea ingens (Zittel, 1864).					l - r
Ostrea chilensis lutaria (Hutton, 1873).					
Divaricella huttoniana (Vanatta, 1901).					
Pteromyrtea dispar (Hutton, 1873).					
Purpurocardia purpurata (Deshayes, 1854).					
Maoricardium spatiosum (Hutton, 1873).					l - r
Pratulum sp.					
Cyclomactra sp.					
Zenatia acinaces (Quoy & Gaimard, 1835).			l - r		
Gari linoleata (Gray, 1835).					
Dosina zelandica Gray, 1835.			t - c		
Dosina sp.					
Bassina yatei (Gray, 1835).					
Tawera subsulcata (Suter, 1905).					
Eumarcia plana Marwick, 1927.					
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).					
Caryocorbula zelandica (Quoy & Gaimard, 1835).					
Barnea (Anchomasa) similis (Gray, 1835).					
Myadora kaiiwiensis Powell, 1931.					
Maoricolpus roseus (Quoy & Gaimard, 1834)					
Stiracolpus sp.			u - r		
Pelicaria n.sp. aff. zelandiae (Marshall & Murdoch, 1920).		u - r			
Taniella planisutularis (Marwick, 1924).			u - r		
Polinices waipipiensis (Marwick, 1924).					
Semicassis (Kahua) fibrata (M & M, 1920).					
Cirsotrema zelebori (Dunker, 1866).					
Austrofusus pagoda (Finlay, 1924).					u - c
Xymene "drewi" (Hutton)					
Amalda (Baryspira) oraria (Olson, 1956).	l - r				
Amalda novaezelandiae (Sowerby, 1859).					
Amalda (Gracilispira) cf. *rimuensis* (Olson, 1956).					
Amalda sp.					
Alcithoe haweraensis Marwick, 1926.				u - r	
Alcithoe cf. *whakinoensis* Marwick, 1926.					
Splendrillia aequistriata (Hutton, 1886).			l - r		
Tomopleura (Maoritomella) cf. *robusta* (Powell, 1942).			l - c		
Fissidentalium zelandicum (Sowerby, 1860).					u - r
Neothyris sp.					
Magasella sanguinea (Leach).					
Fellaster zelandiae (Gray).	t - a				

SHELLBED AT WILKIES BLUFF								
	apm4	apm4	apm4				apm5	apm8
	Waitotara	Waitotara	Waitotara	Ohie	Ohie-Iti	Ohie	Ohie	Okiwa
	Laws '40	GS 4124		GS 4224	GS 4219	GS 4223		
Lunucula wanganuica (Laws, 1940).	x							
Nucula nitidula Adams, 1856.	x	x						
Cosa trigonopsis (Hutton, 1885).	x	x						
Philobrya waitotara (Laws, 1940).	x	x						
Glycymeris (Glycymerula) modesta (Angas, 1879).	x							
Modiolus areolatus (Gould, 1850).		x		x				
Xenostrobus huttoni (Suter, 1914).								l - r
Chlamys gemmulata (Reeve, 1853).	x	x	t - c	x	x	x	t - c	t - a
Phialopecten thomsoni Marwick, 1965.		x	u - r	x	x		t - c	
Patro undatus Gray, 1850.	x	x	u - a	x	x	x		t - a (f)
Limatula maoria Finlay, 1926.	x	x	t - c	x			l - c	l - c (f)
Crassostrea ingens (Zittel, 1864).	x	x	u - a	x	x		u - a (f)	u - a (f)
Ostrea chilensis lutaria (Hutton, 1873).	x	x	u - c	x			t - c	l - c
Divaricella huttoniana (Vanatta, 1901).		x		x				
Felaniella (Zemysia) ampla (Hutton, 1885).		x						
Arthritica bifurca (Webster, 1908).	x							
Arthritica dispar Laws, 1940.	x							
Mylitella finlayi (Marwick, 1924).	x	x						
Melliteryx parva (Deshayes, 1857).	x							
Mysella cf. *tellinula* (Odhner, 1924).	x							
Neolepton antipodum (Filhol, 1880).	x	x						
Pachykellia concentrica Powell, 1927.	x							
Puyseguria wanganuica Powell, 1931.	x							
Pleuromeris finlayi Powell, 1938.	x							
Pleuromeris marshalli (Marwick, 1924).	x	x						l - r
Purpurocardia purpurata (Deshayes, 1854).	x	x	u - c	x	x	x	t - a	l - c
Hamacuna nukumaruensis (Laws, 1940).	x							
Volupicuna laqueus (Finlay, 1926)	x	x						
Talabrica senecta Powell, 1931.	x	x						
Maoricardium spatiosum (Hutton, 1873).	x	x		x	x		l - r	
Trachycardium (Ovicardium) rossi Marwick, 1944.		x						
Cyclomactra aff. *tristis* (Reeve, 1854).		x						
Oxyperas (Pseudoxyperas) komakoensis (Carter, 1972.)		x		x				
Lutraria solida Hutton, 1873.	x	x						
Dosina sp.				x				
Bassina yatei (Gray, 1835).		x						l - r
Tawera spissa aff. *errans* Marwick, 1927.		x				x		
Tawera subsulcata (Suter, 1905).		x				x		
Tawera sp.								l - c
Dosinia (Asa) aff. *lambata* (Gould, 1850).								l - r
Dosinia (Phacosoma) subrosea (Gray, 1835).			u - c					
Eumarcia plana Marwick, 1927.		x			x	x		
Eumarcia (Atamarcia) benhami Marwick, 1927.						x		
Ruditapes n.sp aff. *largillierti* (Phillipi, 1847).				x				
Caryocorbula zelandica (Quoy & Gaimard, 1835).	x							
Panopea wanganuica Powell, 1952.			u - r					
Barnea (Anchomasa) similis (Gray, 1835).								l - r
Hunkydora novozelandica (Reeve, 1859).						x		
Scissurona fossilis Laws, 1940.	x							
Emarginula striatula Quoy & Gaimard, 1834.	x	x						
Tugali pliocenia Finlay, 1926.								l - r
Brookula (Aequispirella) cf. corula (Hutton, 1885).	x							
Brookula (Aequispirella) cf. finlayi Powell, 1933.	x							
Crossea (Crosseola) waitotara (Laws, 1940).	x	x						
Dolicrossea vesca Finlay, 1926.	x	x						
Liotella cf. *rotula* (Suter, 1908).	x							
Micrelenchus aff. *sanguineus sanguineus* Gray, 1843.	x	x						
Micrelenchus n.sp.		x						
Trochus (Coelotrochus) browni (Fleming, 1943).		x						
Trochus (Coelotrochus) tiaratus (Q & G, 1834).	x							
Zethalia zelandica (Hombron & Jacquinot, 1854).	x							
Calliostoma hodgei Hutton, 1875.	x	x						
Argalista fluctuata (Hutton, 1883).	x	x						
Attenuata charassa (Finlay, 1924).	x	x						
Manawatawhia aedicula Laws, 1940.	x							
Pisinna impressa (Hutton, 1885).	x	x						
Pisinna jocosa (Laws, 1940).	x							
Pisinna rekominor (Laws, 1940).	x	x						

Pisinna rugosa (Hutton, 1885).	x							
Pisinna seminsulcata (Hutton,1885).	x	x						
Nozeba emarginata (Hutton, 1885).	x							
Eatoniella (Dardanula) cf. *olivacea* (Hutton, 1882).	x	x						
Elachorbis unicarina Laws, 1940.	x	x						
Caecum (Fartulum) digitulum Hedley, 1904.	x							
Maoricolpus roseus (Quoy & Gaimard, 1834)	x	x	u - r		x	x		l - c
Stiracolpus propagada Laws, 1940.	x	x		x	x			
Stiracolpus huttoni huttoni (Crossman, 1912).	x							
Stiracolpus waikopiroensis (Suter, 1917).	x							
Stiracolpus sp.			u - r					
Zeacolpus vittatus (Hutton, 1873)								l - c
Pelicaria n.sp.		x		x				
Crepidula cf. *costata* Sowerby, 1824.		x						
Crepidula radiata (Hutton, 1873).		x		x	x	x		
Sigapatella novaezelandiae (Lesson, 1830).	x	x	u - r					
Zegalerus cf. crater Finlay, 1926.		x						
Taniella planisutularis (Marwick, 1924).	x	x		x				
Polinices aff. *waipipiensis* (Marwick, 1924).					x			
Ataxocerithium sp.	x	x						
Selia (Hebeselia) bulbosa (Suter, 1908).	x	x						
Specula sp.	x	x						
Cautotriphora simulans Laws, 1940.	x	x						
Eulima christyi Marwick, 1924.	x	x						
Cirsotrema zelebori (Dunker, 1866).	x	x						
Austrofusus taitae (Marwick, 1924).						x		
Penion sp.		x						
"Zafra" impedita Laws, 1940.	x							
Zemitrella cf. *websteri* (Suter, 1913).	x	x						
Zemitrella sp.		x						
Xymene ambiguus (Phillipi, 1844).	x							
Xymene bonneti bonneti (Cossman, 1903).	x	x						
Amalda (Baryspira) mucronata (Sowerby, 1830).	x	x		x				
Amalda (Baryspira) oraria (Olson, 1956).						x		l - c
Amalda novaezelandiae (Sowerby, 1859).								l - r
Lamprodomina neozelanica (Hutton, 1885).						x		
Alcithoe sp.		x						
Duplicaria (Pervicacia) tristis (Deshayes, 1859).	x							
Splendrillia edita Powell, 1942.					x			
Phenatoma rosea (Quoy & Gaimard, 1833).	x	x						
Neoguraleus n.sp.		x						
Oamaruia (Zeadmete) teres Laws, 1940.		x						
Odostomia castlecliffensis Laws, 1939.	x							
Odostomia zecorpulenta Laws, 1939.	x							
Odostomia sp.	x							
Eulimella deplexa Hutton, 1885.	x							
Turbonilla cf. *stoneleighana* Laws, 1937.	x							
Neothyris cf. *obtusa* Thom.				x				
Neothyris sp.			u - r			x	t - c	l - c
Notosaria nigricans				x				

APPENDIX THREE:

PALEOMAGNETIC DATA:

Wanganui River Waipipian-Mangapanian Site Mean Directions.												
		E-6 A/m									polarity only sites	
site	ELEV	NRMave	CLS	POL	N	DECs	INCs	K	alpha-95	lpha-63	dec	inc
S125	1651	42	B	**R**	4	145.3	48.4	24.4	19	11.0		
S124	1516	179	A/B	**R**	4	189.1	44.6	19.9	21.1	12.2		
S123	1476	106	A	**R**	4	177.4	41	3.4	58.9	34.1		
S122	1469	104	D	**R**	4						180	57.5
S121	1363	248	C/D	**N**	4						0	-57.5
S120	1306	102	E		4							
S119	1179	143	C/D	**R**	4						180	57.5
S119a (W113)	1153		B/C	**R**	3	199.7	57.1		11.3			
S118	1142	178	C	**N**	4	16.9	-62	20.1	21	12.2		
S117	952	111	B/C	**N**	4	41.5	-76	39.1	14.9	8.6		
S116	855	124	C	**N**	4	11.1	-60.9	23.1	19.5	11.3		
S115	671	199	D	**N**	4					0.0	0	-57.5
S114	601	93	B/C	**N**	4	-18.1	-60.3	15.7	23.9	13.8		
S113	531	106	B/C	**N**	3	1.7	-44.7	66.2	15.3	8.9		
S112	475	173	B	**R**	5	193.5	46.9	180.1	5.7	3.3		
S111	426	1419	B	**R**	5	173.6	51.6	498.6	3.4	2.0		
S108	391	129	A	**N**	4	8.6	-57.2	31.6	16.6	9.6		
S110	384	1659	A	**N**	5	8.6	-56.2	999.9	1.8	1.0		
S109	368	617	B	**N**	4	6	-50.7	298.4	5.3	3.1		
S107	349	126	B	**N**	4	-12	-53.1	84	10.1	5.8		
S105	198	79	B	**N**	4	-7.9	-65.9	6.8	38	22.0		
S104	145	96	B	**N**	4	47.2	-49.5	67.8	11.2	6.5		
S103	101	1320	A	**R**	5	193.5	48.9	61.3	9.8	5.7		
S102	61	476	A	**R**	5	188.2	48.9	736.6	2.8	1.6		
S101	0	2596	A	**N**	5	9.5	-51.9	351.6	4.1	2.4		

Mangapanian Extra Section Site Mean Directions								
	Dec g	Inc g	Dec s	Inc s	K	alpha-95	Class	Polarity
Rangitatau East Road (Paparangi)								
S132							D	?
S131	151.4	32.3	152.4	28.6	19.5	28.7	B-C	**R**
S130	93.9	-75.4	78.5	-75.5	33.9	21.5	B	**N**
S129	237	60.7	231.1	58.7	9.9	30.8	B-C	**R**
Kauarapaoa								
S126	170.4	53.2	170.4	50.2	22.4	19.8	C	**R**
S133	116.9	73	123.9	71	21.4	27.6	C	**R**
S127	164.7	54.1	165.2	51.2	15.3	46.8		**R**
S133a	161.7	66.9	162.7	64	12.2	18.2	127+133	**R**
S128	328.9	-63.9	331	-61.1	4	53.1	C--	**N**
Rangitikei								
S146	156	68.1	161.4	62.6	27.4	17.9	C	**R**
S145	174.2	57.2	175.3	51.2	5.8	47.7	C	**R**
S142	248.5	28.7	245.7	26.2	59.6	12	B	**R**
S143	192.5	72.4	189.9	66.5	21.4	20.3	B-C	**R**
S144	186.8	49.7	186.3	43.7	31.7	16.6	B-C	**R**
S141	348	-57.2	349.9	-51.4	18	22.2	B	**N**
S140	3.7	-57.9	3	-50.9	721.9	3.4	A	**N**
Whangaehu								
S136	189.8	15.7	189.6	11.3	8.7	44.7	C--	**R**
S135	187.3	37.7	186.9	33.2	19.8	21.2	C-	**R**
S134	192.6	62.2	191	57.8	15.9	32	C-	**R**
S137	340.2	-60.6	342.6	-56.3	28.7	23.4	C--	**N**

Turakina section revised polarities (from McGuire, 1989			
H***series from Wilson, 1993)			
Site	ELEV	Dec	Polarity
H132	1190	0	R
H131	1185	0	R
H130	1180	0	R
H129	1175	0	R
H128	1140	0	R
H128	1130	0	R
H127	1095	0	R
H126	1068	0	R
H125	1057	0	R
99T	1040		R
11U	1028	0	R
97T	1028	0	R
98T	1025		
96T	1024	180	
95T	995	180	R
94T	983	180	R
93T	949	180	R
92T	934	180	R
91T	920	180	R
90T	895	0	N
89T	878	0	N
02U	852	0	N
01U	832	180	R
83T	816	0	N
82T	811	0	N
81T	773	0	N
03U	769	0	N
80T	742	0	N
79T	710	0	N
78T	684	0	N
77T	664	0	N
76T	639	0	N
71T	621	0	N
12U	610	0	N
13U	594	0	N
70T	593		
69T	576	0	N
06U	546	0	N
66T	521	0	N
67T	493	0	N
65T	482	0	N
68T	477	0	N
63T	465	0	N
64T	465	0	N
87T	440	0	N
86T	397		
62T	390	0	N
85T	377	0	N
61T	356	0	N
60T	337	0	N
59T	317	0	N
08U	287	0	N
58T	267	0	N
57T	245	0	N
07U	219	0	N
56T	196	0	N
55T	181		
54T	167	0	N
53T	152	0	N
52T	137	180	R
51T	125		
50T	109	180	R
49T	90		
15U	83	0	N
48T	74	0	N
14U	69	0	N
75T	63		
74T	50	180	R
73T	40	0	N
04U	9	0	N
10U	0	0	N

APPENDIX FOUR:

SITE LOCATIONS AND DESCRIPTIONS.

Site 1 (R22/570553), 2 km north of Waitotara Township. The Mangapani Shell Conglomerate crops out in a gully about 0.5 km north of State Highway 3. Access to this site is 4WD or by foot. A gateway beside a slight dip on a straight section of road leads down to the gully.

Site 2 (R21/660604), Waitotara River valley. The Mangapani Shell Conglomerate crops out prominently on the Waitotara valley roadside.

Site 3 (R21/671613), Mangapunipuni valley. The Mangapani Shell Conglomerate crops out intermittently along the true left valley wall. Park on roadside opposite woolshed and walk up the track on the south side of the valley. 4WD access possible only in extremely dry conditions, and track is in poor condition.

Site 4 (R22/558499; G.S. 4124 of Fleming, 1953), Waitotara River valley. A shellbed cropping out at this site was previously known as the "Shellbed at Wilkies Bluff", but considerable doubt exists as to if it in fact is same unit as the Wilkies Shellbed as it is known in the inland sections and is not classified in this study. Access is probably best by boat, as gorse has overgrown the land access to the base of the section.

Site 5 (R22/633550; G.S. 4223 of Fleming, 1953), Ohie Stream, Oruakainga Road. This shellbed was previously correlated with the Wilkies Shellbed, but this correlation is now dubious and is not classified in this study. The shellbed crops out in the bluffs below the stockyards at the end of the road.

Site 6 (R22/714599), Okiwa Trig. The Gully Shellbed crops out in the large gully on the north face about 100 m south of the aircraft navigation station. Access to navigation station is possible by car. Access to the gully is possible only by foot, by dropping into the top of the gully in the saddle between the two peaks. Difficult to access section, should only be tackled by the fit and agile, in pairs.

Site 7 (R22/714599), Okiwa Trig. Shell horizons within Makokako Sandstone. For access see above site.

Site 8 (R22/714598), Okiwa Trig. The Wilkies Shellbed is clearly visible in the escarpment. For access see site 6.

Site 9 (R22/714598), Okiwa Trig. The Mangamahu Shellbed unconformably overlies the Wilkies Shellbed. For access see site 6.

Site 10 (R22/714597), Okiwa Trig. The Tirotiro Shellbed crops out as a weakly developed shellbed within siltstone at this site, above the Mangamahu Shellbed and below the Te Rama Shellbed. For access see site 6.

Site 11 (R22/706583; G.S. 4189, Fleming, 1953), Rangitatau West Road. The Te Rama Shellbed crops out beside the road about 0.5 km north of the point where the road drops steeply below the Kuranui Limestone.

Site 12 (R22/687569), Windy Point Quarry, Rangitatau West Road, Okiwa. The Kuranui Limestone is superbly exposed at this site. Note that two separate companies work the quarry (one on each side of the small stream bisecting the quarry) and permission is required from each for access. A hard hat is also required for access.

Site 13 (R21/785639), Rangitatau East Road, Paparangi. A thin, poorly developed shellbed occurs within siltstone here.

Site 14 (R21/784637; G.S. 4209 of Fleming, 1953), Rangitatau East Road, Paparangi. The Wilkies Shellbed crops out on the roadside near some large pines.

Site 15 (R21/784636; G.S. 4210 of Fleming, 1953), Rangitatau East Road, Paparangi. The Mangamahu Shellbed crops out a few metres above the Wilkies Shellbed, and the top of the shellbed is marked by fossiliferous sandstone at the base of the next roadside outcrop ~ 50 m south of site 14.

Site 16 (R21/774634), Rangitatau East Road, Paparangi. Fossiliferous siltstone with common *Patro* about 10 m stratigraphically below the Te Rama Shellbed crops out on the roadside here.

Site 17 (R21/773635), Rangitatau East Road, Paparangi. The Te Rama Shellbed is well exposed on the inside of a bend in the road here.

Site 18 (R21/772632), Rangitatau East Road, Paparangi. The Parihauhau Shellbed crops out about 200 m north of the Rangitatau East / Junction Road intersection in a circular slump scarp above the roadside.

Site 19 (R21/763628), Junction Road, Paparangi. The Kuranui Limestone crops out in a quarry here, but vehicle access to the quarry is often blocked by a locked gate. In this case, a walk of about 500 m is required.

Site 20 (R21/846625), Wairangi Station. The Mangapani Shell Conglomerate crops out at the base of a waterfall near the woolshed. Access this site by scrambling down through the bush on the western side of this creek near its confluence with the Kauarapaoa Stream, and then head upstream to the waterfall. The Soulsby Siltstone also occurs at this site, and can be observed at the top of the waterfall between the house and the woolshed.

Site 21 (R21/841617; G.S. 4213 of Fleming, 1953). Wairangi Station. The Wilkies Shellbed crops out beside the track (abandoned Tokomaru East Road) leading up to

Ruawahia and Kaihokahoka Peaks from the buildings at Wairangi. At this point, the track follows along the ridge crest for about 20 metres. Immediately after the ridge crest section, head into the scrub on the eastern side of the track, and continue eastwards along the top of the ridge spur through the scrub for about 50 m. The shellbed crops out on the northern face of this spur, and the buildings of Wairangi Station should be visible from the outcrop itself

Site 22 (R22/902592). Kauarapaoa valley. The Otere Shellbed is well exposed here, but recently planted pine trees will conceal this site in the near future. Cross over the Kauarapaoa Stream on the bridge at the woolshed.

Site 23 (R22/902594; site G.S. 4208 of Fleming, 1953). Kauarapaoa valley. Wilkies Shellbed. This site is about 30 m directly uphill from site 22. Best accessed by heading uphill on the track which begins at a line of poplars.

Site 24 (R22/900581), Kauarapaoa valley. The Wilkies Shellbed crops out just below the road. Park under the Totaras on the outside of the left hand bend and slide down the gut immediately to the south of the Totaras.

Site 25 (R22/906597), Kauarapaoa valley. Te Rimu Sandstone and Mangamahu Shellbed are well exposed in the face on the south side of the unnamed tributary of the Kauarapaoa Stream. Access site by crossing the bridge over the Kauarapaoa Stream beside the woolshed near site 22, and head north on the track on the eastern bank of the Kauarapaoa Stream. This site is within a scalloped section about halfway up the face.

Site 26 (R22/906597), Kauarapaoa valley. The lower Tirotiro Shellbed is exposed near the top of the face, above site 25.

Site 27 (S22/906564), Kauarapaoa valley. The upper Tirotiro Shellbed crops out at stream level on the eastern bank of the Kauarapaoa Stream, about the midpoint of a straight reach. Access: cross the large steel bridge over the Kauarapaoa Stream to the south, and park near the woolshed. A track starting at the stockyards near a bend in the river directly north of the woolshed eventually leads to this site.

Site 28 (S22/904568), Kauarapaoa valley. The lower Tirotiro Shellbed is well exposed beside the road at this site.

Site 29 (S22/908597), Kauarapaoa valley. The upper Tirotiro Shellbed crops out about 200 m east of site 25.

Site 30 (S22/906563), Kauarapaoa valley. The Parihauhau Shellbed crops out at a prominent bend in the steep farm track winding up the ridge between the Waiehu and Kaiwha streams. The Te Rama Shellbed crops out 14 m below this site.

Site 31 (S22/908565), Kauarapaoa valley. The School Shellbed crops out beside a hairpin bend on the farm track. Cross the fence on the outside of the bend and the shellbed is exposed about 20 m to the north of the fence.

Site 32 (R22/898548; G.S. 4198 of Fleming, 1953), Kauarapaoa valley. The Hautawa Shellbed crops out on the roadside about 100 m north of a swing bridge crossing the Kauarapaoa Stream.

Site 33 (R22/902555) Kauarapaoa valley. The Tuha Shellbed crops out above the Upokonui Sandstone about 50 m above the true left bank of the Kauarapaoa Stream. The site can be accessed by crossing the large steel bridge upstream of this site, and following a track on foot southward on the left bank to this site.

Site 34 (S21/930648), Wanganui River valley. The Te Tuhi Shellbed crops out on the roadside here, as the road crests a significant rise.

Site 35 (S21/924633), Wanganui River valley. The Mangapani Shell Conglomerate crops out on the roadside about 2.5 km north of Atene settlement. The outcrop is about 100 m south of a small bronze plaque set into the rock on the east side of the road.

Site 36 (S22/959575), Wanganui River valley. The Otere Shellbed crops out on a disused track on the true left bank of Whauteihi Stream, about 50 m upstream of the road bridge.

Site 37 (S22/960575), Wanganui River valley. The Makokako Sandstone crops out beside the Wanganui River Road, and contains multiple thin shell horizons in its lower part.

Site 38, (S22/954572), Te Rimu, Wanganui River valley. The Wilkies Shellbed crops out spectacularly above the Wanganui River Road here.

Site 39 (S22/953571), Te Rimu, Wanganui River valley. The Cable Siltstone crops out above the Wilkies Shellbed here, beside the Wanganui River Road.

Site 40 (S22/943574; G.S. 4214 of Fleming, 1953). Whakaihuwaka, Wanganui River valley. Te Rimu Sandstone. A small stream flows through a culvert under the road ~ 50 m south of Whakaihuwaka, and a small shellbed occurs in the road cutting at this point.

Site 41 (S22/953572), Te Rimu, Wanganui River valley. The Mangamahu Shellbed is very poorly developed here, as a few *Ostrea* above the Te Rimu Sandstone. Access the site by climbing straight up the bluff about 25 m from the roadside and traversing about 30 m to the east (near suicidal).

Site 42 (S22/957572), Te Rimu, Wanganui River valley. The Tirotiro Shellbed crops out halfway up the eastern spur of the large bluff above the road. The can be accessed by heading up the track cutting through the Wilkies Shellbed, and then heading back westward towards the fence line running down the ridge spur. Cross over the fence about the mid point of the ridge spur at a slightly benched break in slope and hunt around for a narrow goat track on the western side of the fence. The shellbed is about 20 m along this track.

Site 43 (S22/957572), Te Rimu, Wanganui River valley. The Te Rama Shellbed crops out about 20 m above site 42. The shellbed is exposed below a goat track about 30 m west of the fence line.

Site 44 (S22/962572), Wanganui River valley. The Parihauhau Shellbed crops out in a small scarp on this hillside, about 50 m above a bend the farm track. Exposure is generally poor and site is difficult to find.

Site 45 (S22/939543), Wanganui River valley. The School Shellbed crops out at river level on the left bank of the Wanganui River about 100 m south of Parikino School, beneath the Wanganui River Road. Access is difficult, but is possible by scrambling through the gorse and scrub opposite the driveway entrance about 500 m south of the school. Apparently a track is to be built down to the river to the shellbed from the school at some stage, but was not present at the time of this publication.

Site 46 (S22/952548), Wanganui River valley. The Hautawa Shellbed is exposed here above a farm track. The easiest access is by driving through the landowner's driveway immediately north of the Whariki Stream Bridge, and in dry conditions, a car can drive through the paddocks to within about 400 m of the site.

Site 47 (S22/952548), Wanganui River valley. The Upokonui crops out directly above the Hautawa Shellbed here. For access see site 46.

Site 48 (S22/952546), Wanganui River valley. A shellbed cropping out here is loosely correlated with the Piripiri Limestone of Carter (1972).

Site 49 (S22/947543, site 16 of McIntyre & Kamp, 1998), Wanganui River valley. An unnamed Nukumaruan Shellbed crops out here.

Site 50 (S22/984555), Parihauhau. The School Shellbed is well exposed at river level below Parihauhau Road. Access the site by crossing the bridge across the Upokongaro Stream downstream, park at woolshed and walk up track until stream is easily accessible. Then head downstream, and the shellbed is exposed on the true left bank.

Site 51 (S22/982555), Parihauhau. The Hautawa Shellbed is poorly exposed exposed on the western bank of the Upokongaro Stream at this site, above a farm track. For access see site 50.

Site 52 (S22/981555), Parihauhau. The Upokonui Sandstone is well exposed on the western bank of the Upokongaro Stream at this site, above a farm track. For access see site 50.

Site 53 (S22/090580), Mangawhero River valley. The Atene Sandstone crops out beside State Highway 4, with thin shell horizons common in the upper part. It is also exposed in cuttings on the side road intersecting with SH4 at this site.

Site 54 (S22/062537; G.S. 4357 of Fleming, 1953), Mangawhero River valley. The Hautawa Shellbed is well exposed in a prominent bluff about 30 m above State Highway 4.

Site 55 (S22/126546), Whangaehu River valley. The Otere Shellbed crops out in a large bluff above the Whangaehu River at Omahanui. A bridge across the river at Omahanui provides vehicle access, and a 4WD track runs along the base of the bluff.

Site 56 (S22/134541), Whangaehu River valley. The Wilkies Shellbed crops out in the northern part of the large escarpment above a bend in the river 3.5 km north of Mangamahu.

Site 57 (S22/134539), Whangaehu River valley. The Mangamahu Shellbed crops out on the roadside about 200 m south of site 56.

Site 58 (S22/126537), Whangaehu River valley. The Tirotiro Shellbed is exposed in a cliff face on the south side of a natural amphitheatre some ~ 35 m above river level. This feature is known as the "dress circle" by the local population.

Site 59 (S22/126536), Whangaehu River valley. The Te Rama Shellbed crops out in the upper parts of the bluff described above (site 58) but lack of accessibility precludes definitive identification.

Site 60 (S22/153528; G.S. 4362 of Fleming (1953), Creek Road, Mangamahu. The Te Rama Shellbed is well exposed about 20 m north of the Creek Road Bridge.

Site 61 (S22/153528), Creek Road, Mangamahu. The Parihauhau Shellbed is also well exposed about 50-60 m north of the Creek Road Bridge.

Site 62 (S22/148524), Creek Road, Mangamahu. The School Shellbed crops out on the south side of the road below some Macrocarpas.

Site 63 (S22/116529), Whangaehu River valley. The School Shellbed crops out in a large bluff on the true right bank above the Whangaehu River, about 40 m above river level. Access to this site is difficult, and 4WD access only realistically possible in summer or when extremely dry. Can either be accessed from the north at Omahanui (about 4 km to the north) or from Kowhai St, Mangamahu. This route is more accessible via 4WD.

Site 64 (S22/143534; G.S. 4355 of Fleming, 1953), Whangaehu River valley. The Hautawa Shellbed is exposed beside the abandoned "Ridge Road". Access is possible by 4WD in dry conditions, with the track entrance being through the stockyards at Stony Point, about 2 km north of Mangamahu.

Site 65 (S22/120524), Whangaehu River valley. The Hautawa Shellbed crops out above the roadside at this site. While the shellbed cannot be directly accessed, an abundance of float blocks occur below the shellbed.

Site 66 (S22/1225522), Whangaehu River valley. A thin shell horizon at road level occurs within the Tuha Siltstone at this site.

Site 67 (S22/222514), Turakina River valley. The Te Rama Shellbed crops out on the roadside about 1 km north of the intersection of James Road.

Site 68, (R22/217518), Turakina River valley. The Parihauhau Shellbed crops out near the top of the large bluff above the roadside about 1.5 km north of the James Road intersection.

Site 69 (S22/230504; G.S. 4349 of Fleming, 1953), Turakina River valley. The Parihauhau Shellbed is exposed on the roadside immediately south of the road bridge. It is also superbly exposed on the riverbank about 100 m downstream of the bridge at this locality.

Site 70 (T22/325484; G. S. 3096, Fleming, 1953; Site 6 of Naish & Kamp, 1995). West Road, Porewa valley. The Hautawa Shellbed is well exposed here, beside "Old Hautawa Road" (disused) and accessible only by foot or 4WD. The track leading to this site intersects with West Road about 0.5 km before Te Namu Station.

Site 71 (T22/371472), Watershed Road. The Hautawa Shellbed crops out on the west side of the road, capping a low roadside cutting opposite some willows and poplars.

Site 72 (T23/577174; Site 505 of Carter, 1972), Te Ekaou Stream, Komako, Pohangina River valley. The Hautawa Shellbed is in contact with Mesozoic greywacke here, and crops out in the streambed. Access is difficult, and foot only. Park on roadside where Te Ekaou Stream flows under the Pohangina valley East Road, and head eastward upstream on foot for about 2 km.

Site 73 (S21/031616), Parihauhau. The Wilkies Shellbed crops out on the roadside above the Parihauhau School. The site is about 50 m south of a hairpin bend in the road.

Site 74 (S22/016578; G.S. 4205, Fleming, 1953), Parihauhau Road. The Parihauhau Shellbed crops out on the roadside.