Sequence Stratigraphy of Plio-Pleistocene Sediments in Lower Turakina Valley, Wanganui Basin, New Zealand

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ABSTRACT

The Wanganui Basin is a large south westerly facing embayment which contains up to 4000 m of Plio-Pleistocene shallow marine sediment deposited during periodic glacio-eustatic sea-level fluctuations. The basin depocentre has shifted progressively southward over time in response to uplift in the north.

Ten cycles recorded within the late Pliocene to mid-late Pleistocene sediments exposed along the coast at Castlecliff are correlated to lower Turakina Valley, Whangaehu Valley and Rangitikei Valley.

The cyclic basin fill in the study area has been interpreted in terms of sequence stratigraphy. Facies successions of the Transgressive Systems Tract (TST) consist of sediment deposited within shoreface to innermost shelf environments during relative sea-level rise. In the Turakina Valley section, it was found that several depositional sequences show anomalously thick TST's. Where these thick TST's are evident, a relatively thin HST occurs. These anomalously thick TST's occur along the flanks of the Marton Anticline and may represent periods of uplift of the anticline or a significant increase of sediment supply into this part of the basin during relative rises in sea-level.

Type A1 Shellbeds in the Turakina Valley section are particularly well represented and tend to be thicker compared to those at Castlecliff. The increase in thickness towards the east of the basin is attributed to increased sedimentation rate with closer proximity to the axial ranges. The faunal assemblage of Type A1 Shellbeds in the Turakina valley section were found to be similar to those at Castlecliff.

Condensed Mid-cycle Shellbeds (MCS) (= Type B Shellbed) are rich in well preserved *in situ* and near *situ* fauna within a muddy, fine sand or silt matrix. The mid-cycle shellbeds in the Turakina Valley section are thinner than those at the Castlecliff section. This thinning out of the MCS towards the east of the basin is attributed to higher

sedimentation rates. Sediment starved conditions necessary for the development of mid-cycle shellbeds are therefore less pronounced.

A new kind of Type B shellbed was recognised in the Turakina Valley section (Facies TCS-1) and consists of a basal shell conglomerate followed by a muddy phase with abundant, diverse fauna. This type of shellbed appears to succeed a period of uplift on the Marton Anticline or follows a period of increased sediment supply into this part of the basin.

In general, the faunal assemblage of Type B Shellbeds in Turakina Valley was similar to that recorded from the Castlecliff section. The assemblage, however, was more diverse in the Turakina Valley section, perhaps reflecting higher sedimentation and subsidence rates towards the east of the basin.

The Highstand Systems Tract (HST) consists of a thick unit of blue-grey siltstone which represents the latter part of a relative sea-level rise and beginning stages of a relative sea-level fall. The siltstone facies that make up the HST were deposited on the inner and inner-middle shelf. The HST's exposed on the onland section of the Wanganui Basin are incompletely preserved. Similarly, the Lowstand Systems Tract (LST), which would be made up of progressively more terrestrial facies as sea-level falls, is only seen at one site in Rangitikei Valley. Both the upper part of the HST and the LST were eroded away and redeposited as the next rise in sea-level occurred, forming the unconformity that represents the sequence boundary.

In the depositional sequences where sedimentation wasn't affected by uplift on the Marton Anticline or by a diverted sediment source, HST's are considerably thicker compared to those at Castlecliff. This thickening of siltstone units towards the east of the basin reflects an increasing sedimentation rate due to closer proximity to the axial ranges and increasing subsidence rate with respect to the position of the contemporaneous depocentre.

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CHAPTER ONE

INTRODUCTION

1.1 Objectives of Thesis

The aim of this thesis was to investigate the facies and facies architecture of depositional sequences (previously called 'cyclothems') represented in Castlecliffian aged sediment in lower Turakina Valley, and to correlate these to the sequences at Castlecliff, Whangaehu Valley and Rangitikei Valley. Where present, tephras were used for correlation and for determining the approximate age of the formations.

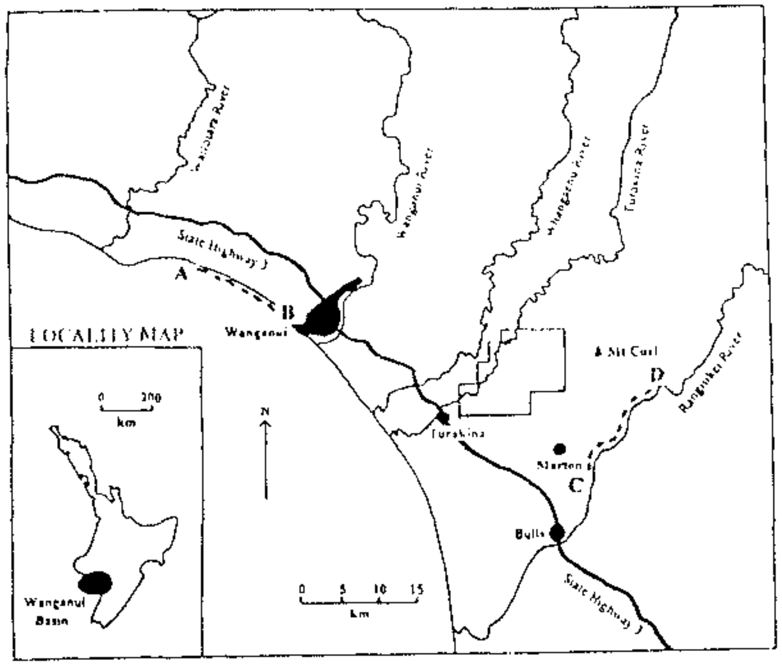
1.2 Thesis Structure

This thesis is comprised of three chapters. Chapter One is an introduction to the study area, regional geologic setting, and also includes a summary of previous work related to sequence stratigraphy. Chapter Two is divided into two parts. Part I defines sedimentary shoreline - shelf environments, sedimentary structures, facies classification and sequence stratigraphy. Part II consists of a detailed description of each depositional sequence of Castlecliffian age observed in Turakina Valley, and includes correlations with sequences from Castlecliff, Whangaehu Valley and Rangitikei Valley. Chapter Three is a discussion of material presented in Chapter Two, Part II. A map and cross-section showing the distribution of the depositional sequences identified in Turakina Valley can be found at the end of this thesis. Both the map and cross-section include various terrace surfaces, the most distinctive of which are the marine terrace surfaces (see section 1.5.1).

1.3 Study Area

1.3.1 Location

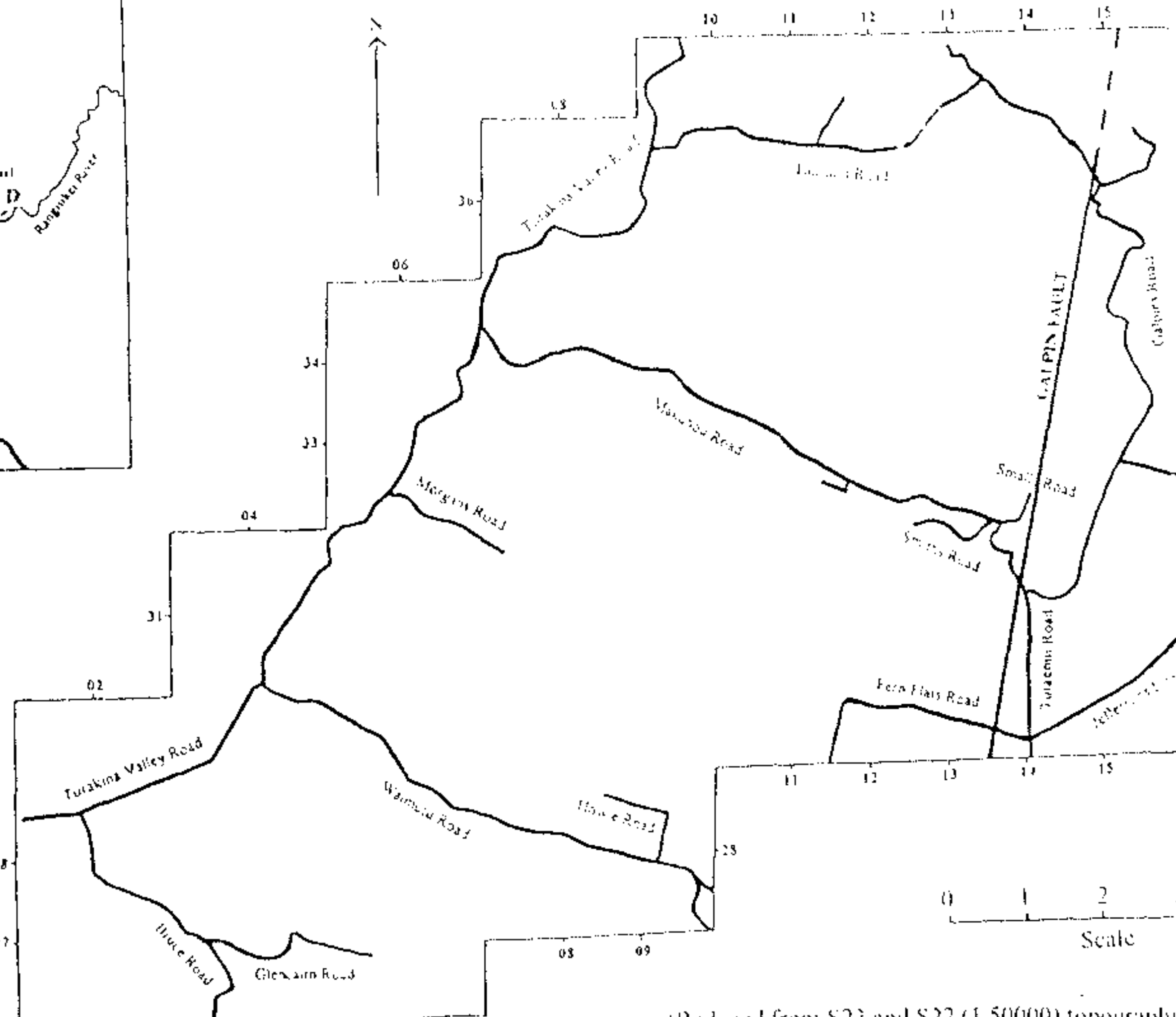
The study site encompasses an area mainly to the east of Turakina River and north-east of Turakina township from Bruce Road to Taurimu Road **[Figure 1.1]**. The complete sequence of Castlecliffian aged deposits in Turakina Valley is generally not well exposed. However, some particularly well exposed sections, although rare in occurrence, did contribute much in determining the overall stratigraphy in the study



A-B Castlecliff Section

C-D Rangitikei Valley Section

Figure 1.1 Location map of study area.



(Reduced from S23 and S22 (1:50000) topographic map sheets) area (Chapter Two, Part II). Approximately 420 m of shallow-marine sediment, comprising 9 depositional sequences (2 - 10) is described in detail. Depositional Sequence 1 was not observed in the study area but is mentioned in Chapter Two, Part II for the sake of completeness. A correlation diagram which includes four stratigraphic columns representing overall sequences from Castlecliff to Rangitikei Valley is included in Chapter Three.

1.3.2 Geological Age

The New Zealand Plio-Pleistocene has been divided biostatigraphically from type sections in the Wanganui Basin sequence. The Castlecliff section is the stratotype of the Castlecliffian Stage (Fleming, 1953). The Plio-Pleistocene boundary lies near the top of the Nukumaruan Stage in New Zealand.

Paleomagnetic data compiled by Turner and Kamp (1990), indicates that the Matuyama/Jaramillo boundary (0.98 Ma) occurs along the unconformity at the base of the Butlers Shell Conglomerate, the Jaramillo/Matuyama boundary (0.91 Ma) is represented by the disconformity below the Okehu Shell Grit, and the Bruhnes/Matuyama boundary (0.78 Ma) lies at the disconformity below the Kaikokopu Shell Grit **[Figure 1.2]**. Pillans *et al* (1994), were able to confirm the position of the Bruhnes/Matuyama boundary proposed by Turner and Kamp (1990), although they did express that caution regarding the position of the lower two reversals was recommended. Pillans (1994) placed the Matuyamu/Jaramillo boundary near the base of the Potaka Pumice based on a recent age of 1 Ma for the Potaka Pumice (Pillans *et al*, 1994).

Figure 1.2 includes correlation of Castlecliffian aged sediment from Castlecliff to Rangitikei Valley and stratigraphic positions and updated ages of volcanic marker beds.

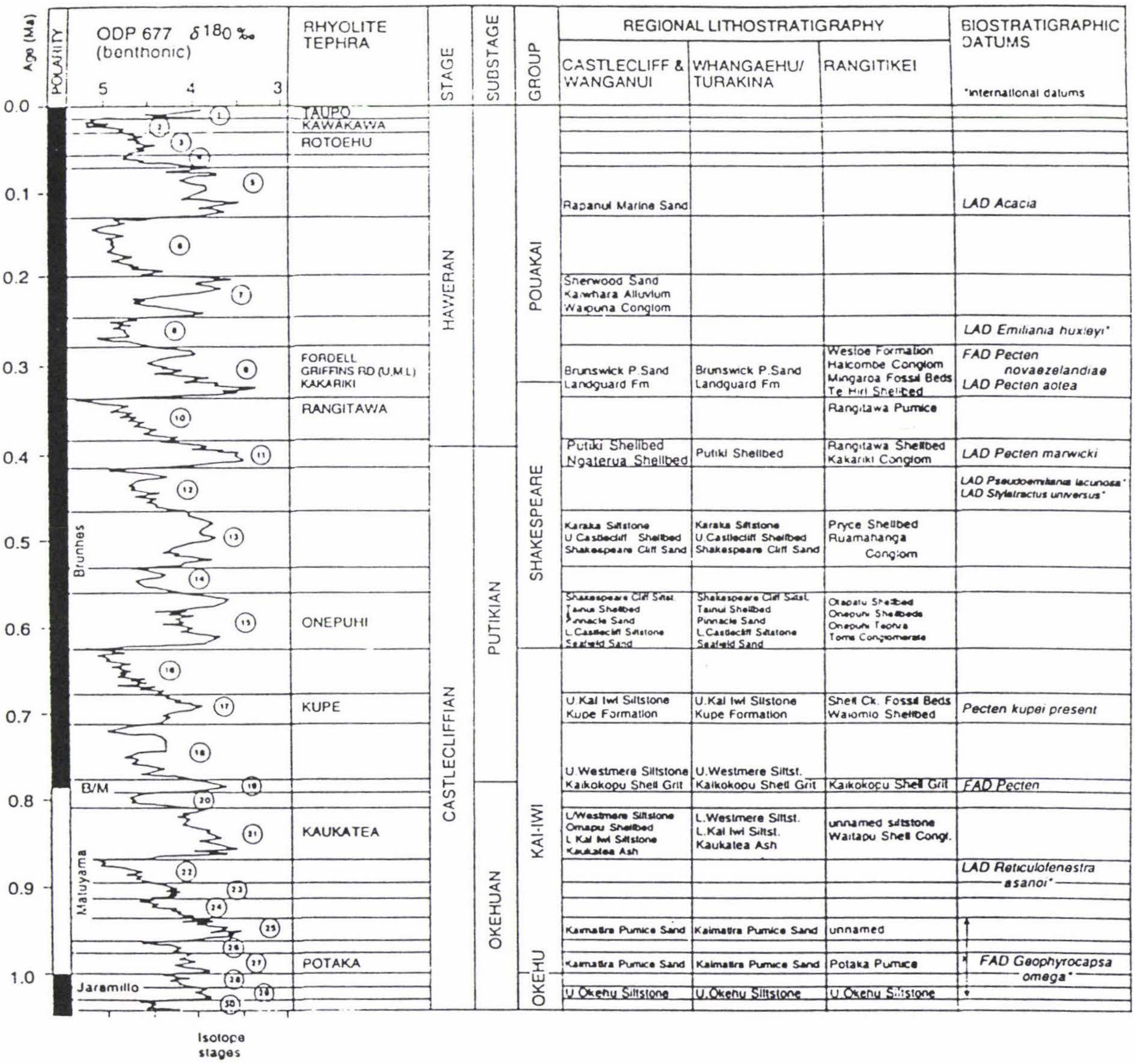


Figure 1.2 Summary of Quaternary stratigraphy in Wanganui Basin over the last 1 Ma. Isotope stratigraphy and magnetic polarity time scale is that of Shackleton *et al* (1990)). See Pillans (1994) for list of other contributors.

1.4 Regional Geologic Setting

The Wanganui Basin is a Plio-Pleistocene basin bounded to the east by the Ruahine and Tararua Ranges which are thought to have been uplifted predominantly during the Pleistocene. To the west, the Wanganui Basin is separated from the South Taranaki Basin by the Patea - Tongaporutu High, a basement high defined by gravity and seismic data (Hunt, 1980). To the north, the Plio - Pleistocene sediments of the basin offlap from the Miocene strata of the northern part of the Wanganui Basin, and to the south they thin and onlap the exposed basement rocks of the Marlborough Sounds (Anderton, 1981) **[Figure 1.3]**

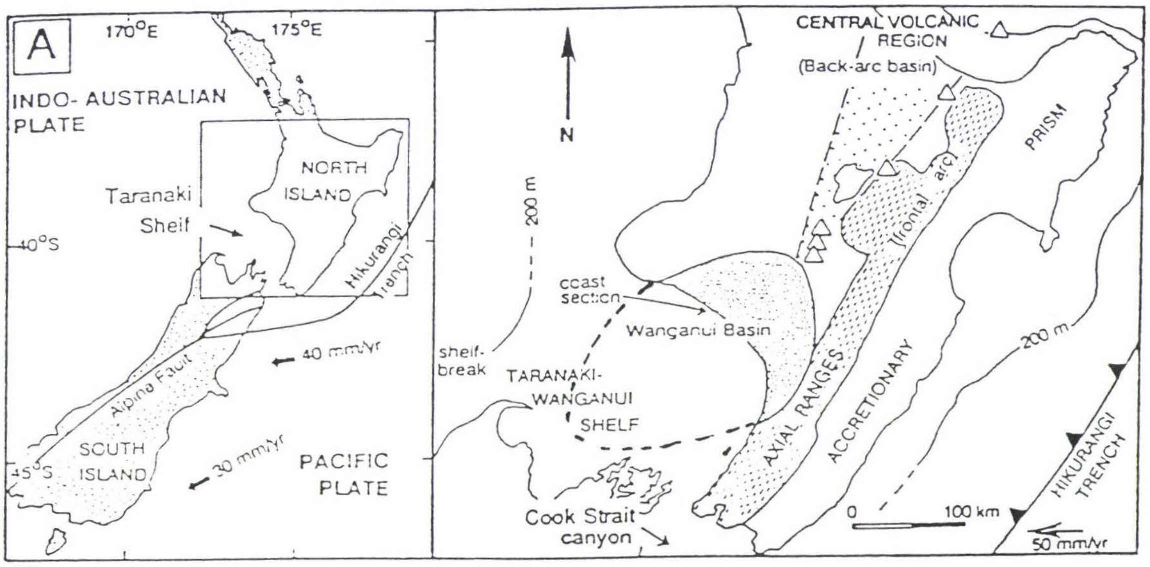
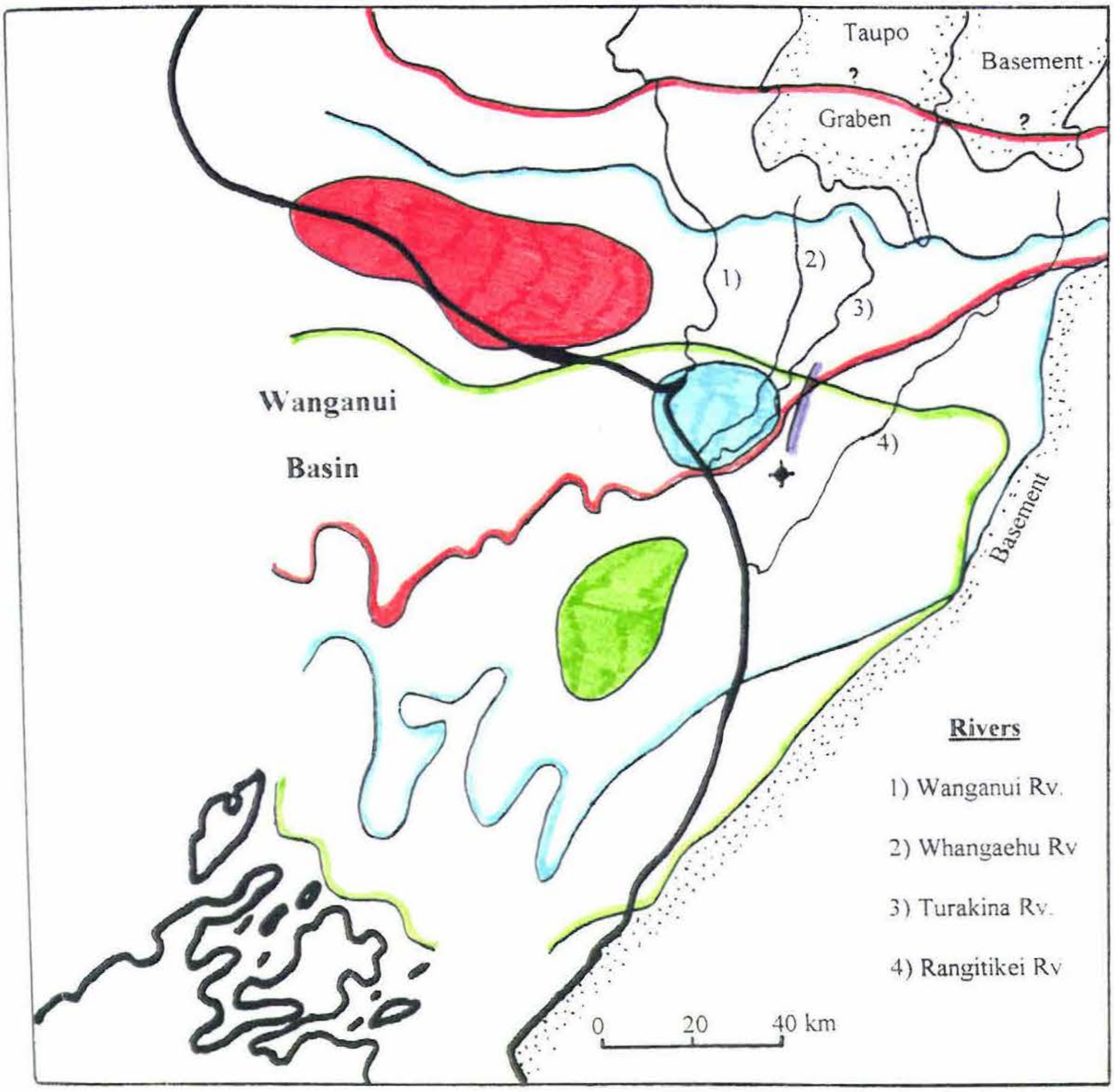


Figure 1.3 Location and geological setting of the Wanganui Basin (Stern and Davey, 1989)

The Wanganui Basin is actively subsiding behind the Hikurangi Subduction Zone due to collision of the Indo - Australian and Pacific Plates. The area now occupied by the basin was largely emergent during the Miocene, when deposition was predominantly in the northern regions of the basin. The centre of subsidence and deposition (the depocentre) moved south during the Plio - Pleistocene, burying the pre-existing topography **[Figure 1.4]**. Subsidence in the south has been matched by uplift in the north, tilting about a southward migrating east-west trending hingeline (Pillans, 1983). Anderton (1981), noted that the southward migration of the depocentre seemed consistent with the southward movement of the Hikurangi Subduction Zone and considered the possibility that the basin was a southern continuation of the Taupo Graben, and therefore extensional. Stern *et al* (1993) proposed a flexural downwarp model, where the downwarping was caused by shear stresses along the interface with the subducting Pacific Plate. They argued that gravity and deep reflection data did not show sufficient crustal thinning to allow for extension - related subsidence. The depocentre currently



Early Pliocene

Late Pliocene - Early Pleistocene

Late Pleistocene

Crest of the Marton Anticline

Stantiall-1 Well

Figure 1.4 Map of the Wanganui Basin showing approximate limits of depocentres and present distribution of early Pliocene, late Pliocene - early Pleistocene, and mid - late Pleistocene sediments (After Anderton, 1981).

lies offshore of the Rangitikei Valley area. The depocentre was calculated to be moving at a rate of 10 mm/yr by Anderton (1981) **[Figure 1.4]**.

Seismic reflection data indicates that basement is comprised of a series of faulted blocks (Anderton, 1981). The basement is overlain by approximately 4000 m of Plio - Pleistocene, shallow-marine sediment. Most of the sediment in the basin was derived from erosion of uplifted basin sediment to the north, with increasing sedimentary input from erosion of the axial greywacke ranges. Eruptive material from the Taupo Volcanic Zone also contributed to the basin fill (Seward, 1974).

1.5 Structural Setting Within The Study Area

Two prominent structural features occur within the study area. The Marton Anticline and Galpin Fault **[Figure 1.4]** were formed due to deformation of basement rocks (Anderton, 1981). The basement structure of the offshore portion of the Wanganui Basin is known from seismic reflection data **[Figure 1.5]** interpreted by Anderton (1981). Onshore, the only data available about depth to basement is from a strip of land along the coast and from four wells drilled in the Wanganui region. The Stantiall-1 well **[Figure 1.4]** near to the Galpin Fault, was drilled to basement at 2080 m (Fleming, 1953). The Marton Anticline appears to result from the monoclinal drape of Plio-Pleistocene sediments over concealed basement faults (Anderton, 1981) **[Figure 1.5]**, rather than as long - wavelength folding due to compression over the basin. The Potaka Pumice (basal member of the Kaimatira Pumice Sand) serves as a good laterally continuous horizon along the anticline from the west of Turakina Valley (43 m asl), to the crest of the anticline at the top of Makuhou Road (257 m asl) **(Appendix D)**. This 214 m vertical rise over a west-east distance of c. 7 km mirrors the monoclinal folding of the base of the Castlecliffian, over the reverse basement faults of the Turakina Fault System (Hellstrom, 1993) **[Figure 1.5]**. The seismic data was taken 30 km to the south of Makuhou Road and the greater offset indicated by these data compared to the height measurements along Makuhou Road, suggests that the throw across the Turakina Fault System decreases to the north (Hellstrom, 1993). Hellstrom (1993) attributed the right fault line in **Figure 1.5** to the Galpin Fault, which is down thrown as much as 500 m to the east

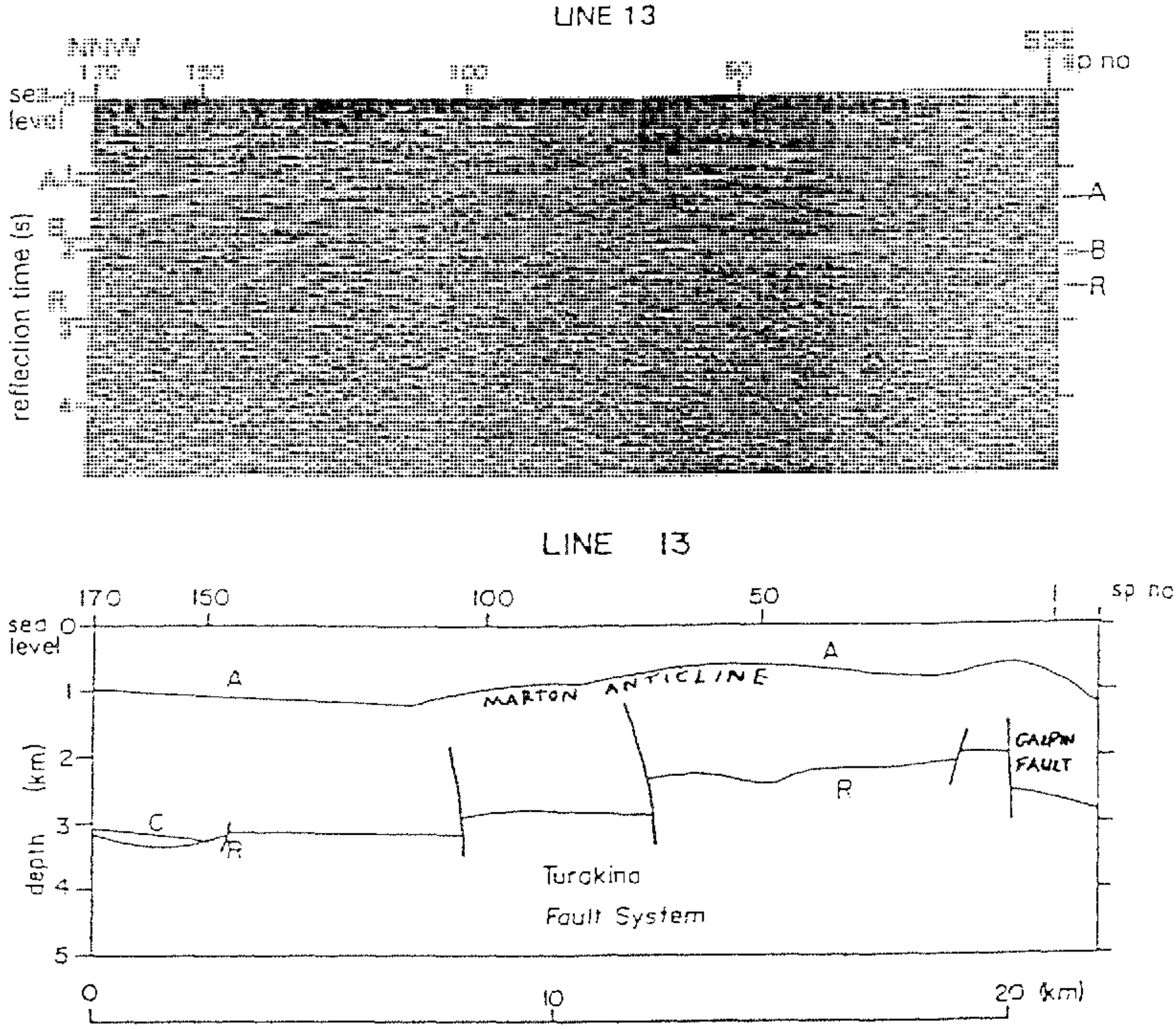


Figure 1.5 Seismic Line 13, onshore Wanganui Basin with a depth section produced by Anderton (1981). The A horizon is near the top of the Nukumaruan Stage and the R horizon is the basement unconformity.

1.5.1 Geomorphology

A number of uplifted, planar marine terrace surfaces occur within the study area but become increasingly dissected with distance away from the coastline. Over time, a combination of uplift and fluvial erosion has eroded the terraces farther inland. To the east of Galpin Fault, both marine terrace and alluvial terrace (formed by Rangitikei River) surfaces occur. These terrace surfaces are represented on the map and cross-section at the end of this thesis.

Streams in the study area generally run east-west, merging with the Turakina River. The east-west flow is attributed to uplift along the Marton Anticline. Where the Marton Anticline has had most influence, north of Bruce Road, north - facing, near vertical scarps with associated large landslides, are common. These scarps were most likely formed by southward migration of the east-west flowing streams, caused by increased uplift rates towards the axial ranges.

1.6 Stratigraphy

1.6.1 Previous Work

Studies of the Plio-Pleistocene sequence of the Wanganui Basin date back to the mid 1800's. However, the first detailed stratigraphy was compiled by Fleming (1953), as part of a regional geological study of the Wanganui and Waverley Survey districts. Fleming used the Castlecliff section as the stratotype for the Castlecliffian Stage and presented a complete history of previous work in the Wanganui district, prior to 1953.

Little has been published on the stratigraphy and sedimentology of the Wanganui Basin since. Most effort has been directed towards dating and chronostratigraphic correlation, initiated by the paleomagnetic, fission-track dating, and isotopic studies of Seward (1974, 1976, 1978, 1979). Application of these methods, with the addition of chemical fingerprinting of tephra horizons, continues to be a focus of research in the Wanganui Basin, especially with regard to correlation with deep sea cores and international oxygen isotope stages (Beu and Edwards, 1984; Kamp and Turner, 1990; Pillans *et al*, 1994; Pillans, 1994).The only detailed sedimentological work to date was carried out by Seward (1974) as part of a basin - wide study of the Okehu Group and more recently by Abbott and Carter (1994) and Abbott (1992, 1994) with application of the Sequence Stratigraphic Model of Carter *et al* (1991).

1.6.2 Sequence Stratigraphy

Fleming (1953) was the first to note the cyclothemic nature of Plio-Pleistocene sediments in the Wanganui sequence. He attributed the cause to relative sea-level changes caused by tectonic processes. The link to glacio - eustacy was made by Fleming (1975a) soon after it was proposed that the Plio-Pleistocene was characterised by repeated glacio - eustatically controlled sea-level fluctuations (Shackleton and Opdyke, 1973). Sediments in the Wanganui sequence were deposited during interglacial periods of high sea-level (Beu and Edwards, 1984), in shoreline to shelf environments within a broad embayment.

In the United States, during the 1970's and 1980's, much work was done to come up with a better interpretation of basin-fill. The analysis of basin-fill sediments was interpreted from seismic profiles and sedimentary cycles, delineated by unconformities, which were visible on seismic lines. These sedimentary cycles were termed 'depositional sequences' (see Chapter Two, Part I), and the study of cyclic basin-fill became known as 'sequence stratigraphy' (Vail *et al*, 1977).

Carter *et al* (1991) applied this technique to the Castlecliff section near Wanganui. They emphasised that sequence stratigraphy can be resolved into two models. Firstly, the Global Sea-level Model (GSM) predicts that deposited sequences are controlled by global (eustatic) changes in sea-level, such that they can be correlated world-wide. Secondly, the Sequence Stratigraphic Model (SSM) predicts the facies composition and sedimentary architecture developed within a depositional sequence during one complete cycle of relative sea-level change. Although sequence stratigraphy was initially developed from seismic reflection profiles, the reinterpretation of cyclic strata in outcrop in terms of the SSM was attempted for the Castlecliff section by Carter *et al* (1991), Abbott and Carter (1994), and Abbott (1994).

In this thesis, this technique is applied to Plio-Pleistocene cyclic basin-fill in Turakina Valley. Because units within the Wanganui sequence are to a large extent laterally continuous, it has been possible to correlate depositional sequences from Castlecliff to Turakina Valley and beyond to Rangitikei Valley (Abbott, 1994; Pillans *et al*, 1994).

Cyclic Plio-Pleistocene strata are also well documented in the Wairarapa and Hawkes Bay (Vella, 1963; Beu and Edwards, 1984; Haywick *et al*, 1992). These areas, including the Wanganui district, provide a good basis for application of the SSM for reasons outlined in Carter *et al* (1991), and included here:

1) Rates and magnitudes of Plio-Pleistocene glacio-eustatic sea-level fluctuations, which can be delineated from oxygen isotope studies of deep sea cores, are almost certainly the dominant driving force of cyclic sedimentation. This means that sedimentary cyclicity, unlike older strata, can be modelled with regard to an independently derived glacio-eustatic sea-level curve.

2) Confidence in paleoenvironmental interpretation of sedimentary facies is high, as most Plio-Pleistocene lithofacies and fossil faunas have close analogues in modern New Zealand shoreline and shelf environments.

1.6.3 Plio-Pleistocene Sea-level Fluctuations

The orbital forcing of climate is considered the cause of sea-level fluctuations (Hays *et al*, 1976). The Plio-Pleistocene world-wide is characterised by numerous glaciations resulting in glacio-eustatic sea-level fluctuations. Oxygen isotope data obtained from deep-sea cores reflects these climatic changes and saw-toothed sea-level curves can be developed to represent these data. The sea-level curve used in this thesis is that of Shackleton *et al* (1990) from Deep Sea core ODP 677 **(see Figure 1.2)**.

Sixth Order (40,000 yr) cycles which reflect the changes in the Earth's obliquity, were evident before 0.85 Ma (Oxygen Isotope Stage 25), while Fifth Order (100,000 yr) cycles, corresponding to the Earth's orbital eccentricity, make up the curve post 0.6 Ma (Oxygen Isotope Stage 16). The 5th Order cycles are characterised by higher amplitude and lower frequency. The 0.3 Ma between the 5th and 6th Order cycles is transitional (Williams *et al*, 1988). Over the last 0.8 Ma, the sea-level curve indicates there was generally a rapid sea-level rise (10-15 m/1000 yr) followed by a slow fall in sea-level (1-1.5 m/1000 yr) (Williams, 1988).

CHAPTER TWO

STRATIGRAPHY

PART I

INTRODUCTION

2.1.1 Continental Shelf Environments

2.1.2 Definition and Interpretation of Sedimentary Structures

2.1.3 Introduction to Sequence Stratigraphy

2.1.4 Classification of Facies

2.1.5 Classification of shellbeds

2.1.6 Pecten Zones

2.1.1 Continental Shelf Environments

Past literature which defines environments on the continental shelf (Reading, 1978; Reineck and Singh, 1975; Abbott and Carter, 1994; Abbott, 1994), has led to some confusion with regard to the terminology used to define each environment. Such terms as foreshore, backshore, transition zone, offshore, nearshore, innermost shelf, inner shelf, middle shelf have all been used to designate continental shelf environments. It is therefore necessary to clarify the terminology used here before embarking on any classification of facies found in these shelf environments.

Due to the fact that Abbott's (1994) Wanganui facies classification has been closely followed in this thesis (section 2.1.4), his shelf terminology has also been adopted. Abbott used such terms as 'shoreface' and 'shelf', although the terms 'nearshore' and 'offshore' were also used (Abbott, 1994; Figure 3-7), which appear to have been taken from the work of Abbott and Carter (1994).

Abbott's shoreface environment encompasses the foreshore and shoreface environments as described by Reading (1978) and Reineck and Singh (1975) **[Figure 2.1.1]**.

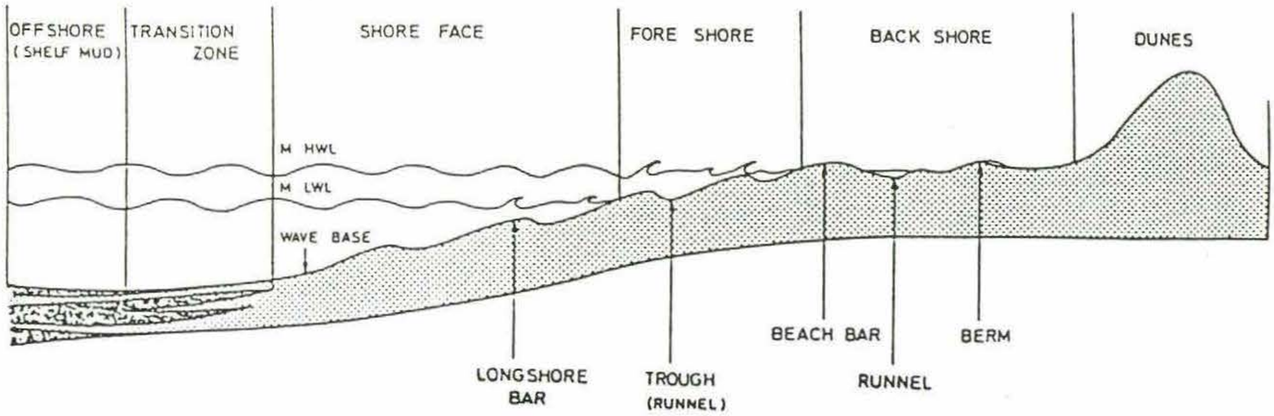


Figure 2.1.1 Diagram showing terminology used to designate shelf environments; after Reineck and Singh (1975) and Reading (1978).

The upper limit of Abbott's shoreface environment therefore is the beachfront (including the swash zone) at high water level (high tide) while the lower limit is placed at the fair weather wave base. Thus the entire shoreface environment is above wave base. The term 'nearshore' is used in Abbott (1994, e.g. Figure 3-7) and in Abbott and Carter (1994) to designate a zone which Abbott also labelled as the innermost shelf in his facies classification section **[see Figure 2.1.4]**. Abbott and Carter's nearshore environment or Abbott's innermost shelf environment have also been called the transition zone by Reading (1978) and Reineck and Singh (1975). The term 'nearshore' is also often used synonymously with the term 'shoreface' (Reineck and Singh, 1975; Reading, 1978) **[see Figure 2.1.4]**.

Abbott (1994) uses the term 'shelf' synonymously with the term 'offshore' (Reading, 1978; Reineck and Singh, 1975), indicating the area on the shelf below fair weather wave base. He describes three sub-environments within his shelf (offshore) environment; the innermost shelf, the inner shelf and the middle shelf **[see Figure 2.1.4]**.

2.1.2 Definition and Interpretation of Sedimentary Structures

Many primary and secondary sedimentary structures were observed within sediments in Turakina Valley. All sedimentary structures originated from shallow marine shelf environments. Definitions of the thickness of 'beds' and 'laminae' are included below.

Laminae: 1 mm - 30 mm		(Reineck and Singh, 1975)
Beds: 10 mm - 1 m +		
mm bedded	1 mm - 10 mm	
cm bedded	10 mm - 0.1 m	(Andrews, 1982)
dm bedded	0.1 m - 1 m	
m bedded	1 m - 10 m	

Primary Sedimentary Structures Observed in Lower Turakina Valley:

- Plane-parallel lamellae
- Cross-bedding
- Flaser, wavy, lenticular bedding and streaky lamination
- Massive bedding
- Graded bedding

Plane-parallel lamellae:

Parallel laminated sand is composed of horizontal layers, usually 1 - 2 mm thick. Lamellae may be laterally continuous for up to 2 m and are generally marked by alternating layers of different grain size, heavy mineral content, or both (Reineck and Singh, 1975). The occurrence of parallel lamellae is generally restricted to fine- and medium-grained sand and this sedimentary structure is commonly deposited within the shoreface zone, where wave action is too severe to allow ripples and megaripples to form. Parallel lamellae are also commonly found within the transition zone from shoreface sand to offshore mud and are also found in the lower shoreface zone toward the inner shelf (transition zone) where bioturbation is more pervasive, texture is finer, allowing parallel lamellae to become the dominant sedimentary structure.

Cross-bedding:

- Small-scale cross-bedding: individual units are only a few mm to a maximum of 50 mm thick (ripple bedding).
- Large-scale cross-bedding: individual units are usually more than 50 mm thick and may be up to 1 - 2 m (mega-ripple bedding).

A cross-bed can be defined as a single layer, or a single sedimentation unit consisting of internal laminae (foreset laminae) inclined to the principal surface of sedimentation. This sedimentation unit is separated from adjacent layers by a surface of erosion, non-deposition, or abrupt change in character (Reineck and Singh, 1975). There are three main forms of cross-bedding based on the character of the bounding surface:

1) Planar cross-bedding: a cross-bedded unit whose bounding surfaces form more or less planar surfaces. These units are generally tabular or wedge - shaped **[Figure 2.1.2a]**.

2) Trough cross-bedding: a cross-bedded unit whose bounding surfaces are curved surfaces and the units are trough - shaped **[Figure 2.1.2b]**.

3) Herringbone cross-bedding: is a special kind of cross-bedding where foreset laminae are laid down in opposite directions in adjacent positions. When the two opposite dipping units are separated by a thin mud layer, an environment strongly affected by tides is indicated (Reineck and Singh, 1975) **[Figure 2.1.2c]**.

Small - scale cross-beds are usually generated through the migration of ripples in a shallow marine shelf environment, although they can also be found within terrestrial environments (e.g. fluvial). In a shelf environment, ripples are formed by the action of wave and tidal currents on the sediment surface. A discussion of wave and tidal currents can be found in Reineck and Singh (1975). The general term 'ripple-bedding' is proposed to include all bedding types produced as a result of the activity of ripples. It includes small-ripple bedding, megaripple bedding, wave-ripple bedding and rippled sand lenses of lenticular and flaser bedding (Reineck and Singh, 1975).

Flaser, wavy, lenticular bedding and streaky lamellae:

Flaser bedding: ripple-bedding with numerous mud flasers is identified as flaser bedding. This sedimentary structure implies that both sand and mud are available and that periods of current activity alternate with periods of calm. During current activity, the sand is transported and deposited as ripples, while mud is held in suspension. When the current pauses, the mud in suspension is deposited mainly in the troughs or may completely cover the ripples. At the beginning of the next cycle, ripple crests are eroded away and new sand is deposited in the form of ripples, burying and preserving ripple beds with mud flasers in troughs (Reineck and Singh, 1975) **[Figure 2.1.2d]**.

Wavy bedding: mud and sand layers alternate and form continuous layers. Mud layers almost completely fill the troughs and make a thin cover over ripple crests so that the surface of the mud layer only slightly follows the concavity and convexity of the underlying ripple surface. The ripple-bedded sand layers of wavy bedding are vertically discontinuous and isolated (Reineck and Singh, 1975) **[Figure 2.1.2e]**.

Lenticular bedding: in lenticular bedding, the ripples or sand lenses are discontinuous and isolated in a vertical as well as horizontal direction. Ripples are therefore produced in the form of isolated lenticular bodies on a muddy substratum. Lenticular bedding is produced under conditions more favourable for the deposition and preservation of mud than for sand. The sand supply is so small that only incomplete ripples are formed (Reineck and Singh, 1975) **[Figure 2.1.2f and g]**.

Streaky lamellae: occur within environments where mud is the dominant sediment deposited. Thin, discontinuous lamellae of very fine sand - coarse silt within the mud are known as streaky lamellae. Sand supply is almost negligible so that ripples are unable to form. Streaky-lamellae are attributed to storm activity; erosion and resuspension of the sea floor by waves and currents which entrain silt and sand as bedload and silt and clay as suspended load and which are subsequently deposited as a silt/mud couplet (Abbott. 1994).

Massive bedding:

Massive bedding generally occurs as large formations of massive blue-grey siltstone within the study area. Primary bedding is usually not visible although it may be present on a minute-scale, only detectible with the use of a microscope. Primary bedding may also not be visible due to bioturbation. The occurrence of massive sandstone in the study area is very infrequent. Absence of primary bedding structures may result from rapid deposition from a decelerating, heavily sediment - laden current.

Graded bedding:

Graded bedding is most likely the result of changes in the hydrodynamic regime. Fining up sequences generally reflect a decelerating current where time is allowed for sediment to settle and sort.

Secondary Sedimentary Structures Observed in Lower Turakina Valley:

- Deformation structures (load structures)
- Bioturbation/Burrowing

Deformation structures:

In the Turakina Valley sequence, deformation structures are most commonly found within dm - bedded muddy siltstone facies. These deformation structures are generally in the form of large (up to 1 m) convolute beds which were most likely formed due to rapid sedimentation and loading, forcing water to be expelled from underlying sediment **[Figure 2.1.2h]**.

Bioturbation/Burrowing:

The occurrence of bioturbation and burrowing by marine organisms is a common feature within the Turakina Valley sequence; most often seen at sequence boundaries and within siltstone facies.

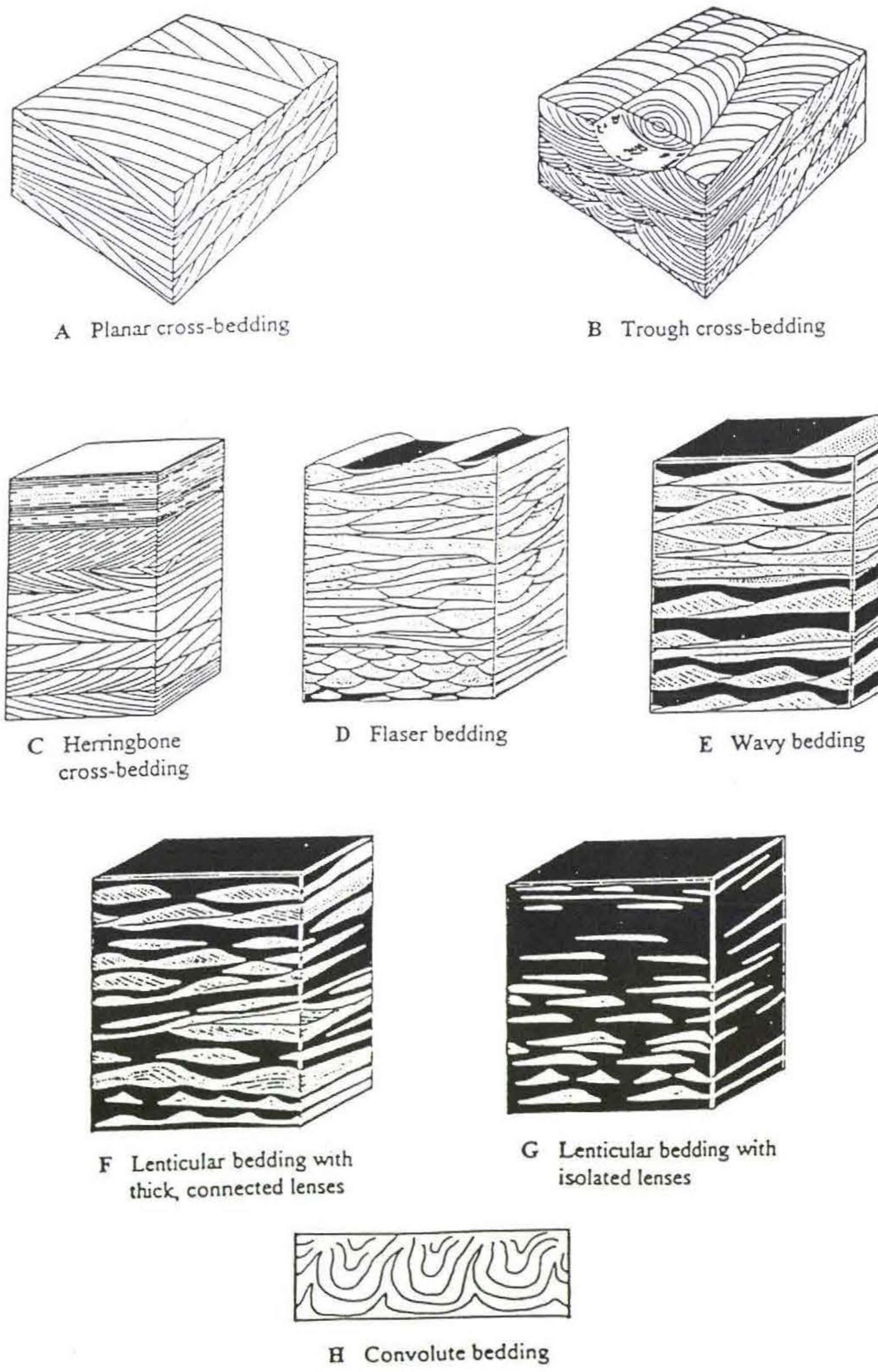


Figure 2.1.2 Types of sedimentary structures observed in the Turakina Valley section (diagrams from Reineck and Singh, 1975).

2.1.3 Introduction to Sequence Stratigraphy

Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata, bounded by surfaces of erosion or non - deposition, or their relative conformities (van Wagoner *et al*, 1988). The fundamental unit in sequence stratigraphy is the **depositional sequence**, defined as a relatively conformable succession of genetically related strata bounded by unconformities and their relative conformities (Mitchum *et al*, 1977). Sequences are interpreted to form in response to the interaction between eustacy, subsidence and sediment supply (van Wagoner *et al*, 1988).

Sequences are divided into **systems tracts**, which are packages of sediment delineated by their position within a sequence, the nature of their bounding surfaces, stratal relationships of their bounding surfaces, and the pattern of internal parasequence stacking and facies succession (van Wagoner *et al*. 1988, Posamenteir and Vail, 1988). In a complete depositional sequence, three systems tracts occur; **transgressive (TST), highstand (HST) and lowstand systems tracts (LST)**. A muddy shellbed with a concentration of often well - preserved fauna is located in the mid - cycle position and is therefore referred to as the **mid - cycle condensed shellbed (MCS)**. These systems tracts and associated mid - cycle shellbed, represent a sea level rise and subsequent fall. In the Pleistocene Wanganui Basin sequences, the lowstand systems tract (elsewhere composed of subaerial deposits) is not represented due to erosion (wave planation) by the ensuing transgression. This wave - planed surface represents a significant unconformity and forms the **sequence boundary** at the base of each cycle. A **ravinement surface** (Swift, 1968 and Nummedal and Swift, 1987) formed by ravinement of the shelf as sea-level drops to its lowest point, is sometimes superimposed on the sequence boundary **[Figure 2.1.3]**.

Transgressive Systems Tract (TST)

As sea - level rises, wave action scours underlying sediments forming the sequence boundary. Above this sequence bounding unconformity, sediments of the TST are laid down. The basal deposits of the TST typically consist of cross - bedded shell conglomerate (Facies HE-1, Type A1 Shellbed, see section 2.1.5), followed by deposition of other Heterolithic Association facies and/or Well - Sorted Sand Association facies **[Table2.1.1, Figure 2.1.3 and 2.1.4]**.

Mid - cycle Condensed Shellbed (MCS)

A mid - cycle disconformity or unconformity generally occurs at the base of the MCS and is referred to as the **Local Flooding Surface (LFS)** (Nummedal and Swift, 1987). The LFS represents a period of maximum starvation caused by the landward movement of the depocentre and therefore rapid deepening during a sea-level rise (Vail *et al*, 1984). Where the LFS is very sharp, erosion and planation of the sea floor, possibly by storm or tidal currents, results in the formation of an unconformity. Following this unconformity is a mid - cycle condensed shellbed, consisting of facies of the Condensed Shellbed Association **[Table2.1.1]**, indicative of deposition on a sediment starved inner shelf **[Figure 2.1.3 and 2.1.4]**. The MCS is interpreted to form within a period of continued transgression following deposition of facies successions of the TST (Abbott, 1994). The MCS corresponds to a Type B Shellbed (section 2.1.5).

Highstand Systems Tract (HST)

A mid - cycle disconformity may occur at the base of the HST, located at the upper surface of the MCS and this disconformity corresponds to the **Downlap Surface (DLS)** (Vail *et al*, 1984). The DLS is the point which marks the influx of shore-derived fine - grained sediment which is deposited progressively seaward on the shelf following a period of sediment starvation (Abbott and Carter, 1994). The HST consists of facies of the Siltstone Association (**Table 2.1.1**, section 2.2.4) which represent deposition on the inner and inner - middle shelf **[Figure 2.1.3 and 2.1.4]**. The HST is interpreted to be deposited during the late part of a eustatic sea - level rise and the early part of a sea - level fall (van Wagoner *et al*, 1988, Posamenteir and Vail, 1988). It has not been determined exactly where to place the point of maximum flooding; termed the **Maximum Flooding Surface (MFS)** . It was originally placed at the top of the MCS, however, another alternative is that it lies somewhere within the HST but is not represented by a distinctive surface such as a disconformity. The HST is truncated by the sequence bounding unconformity at the base of the next sequence (van Wagoner et al. 1988).

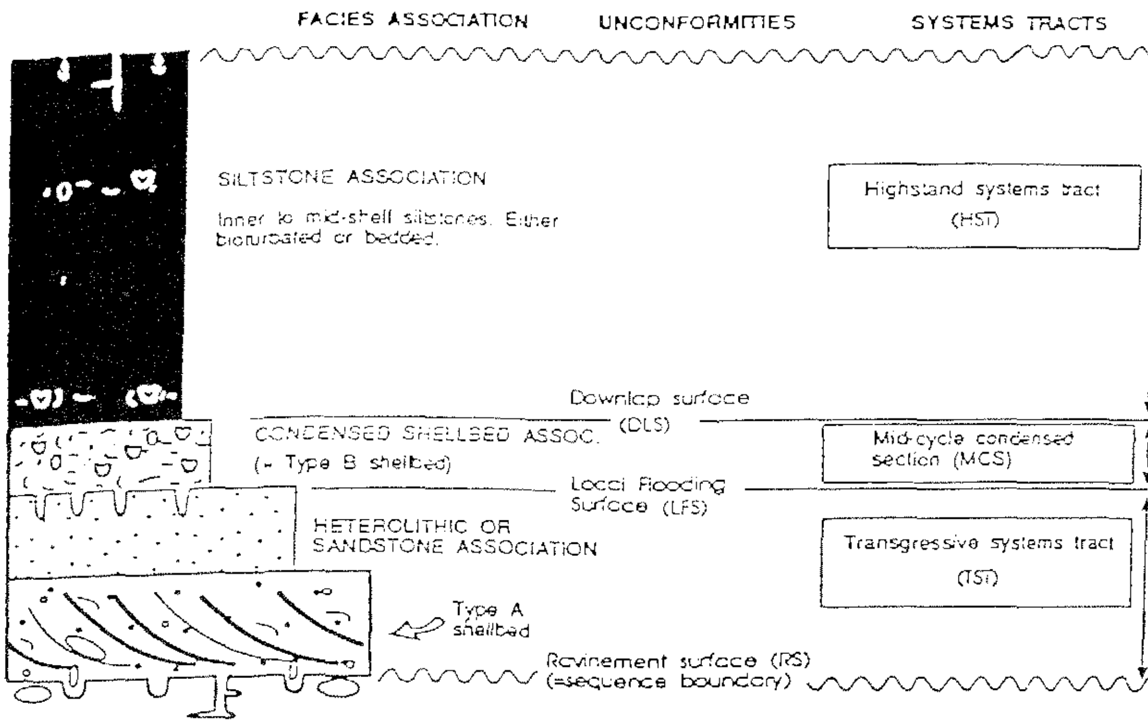


Figure 2.1.3 Idealised diagram of a Wanganui Basin mid-Pleistocene depositonal sequence, summarising terminology related to systems tracts and their bounding surfaces (Abbott, 1994).

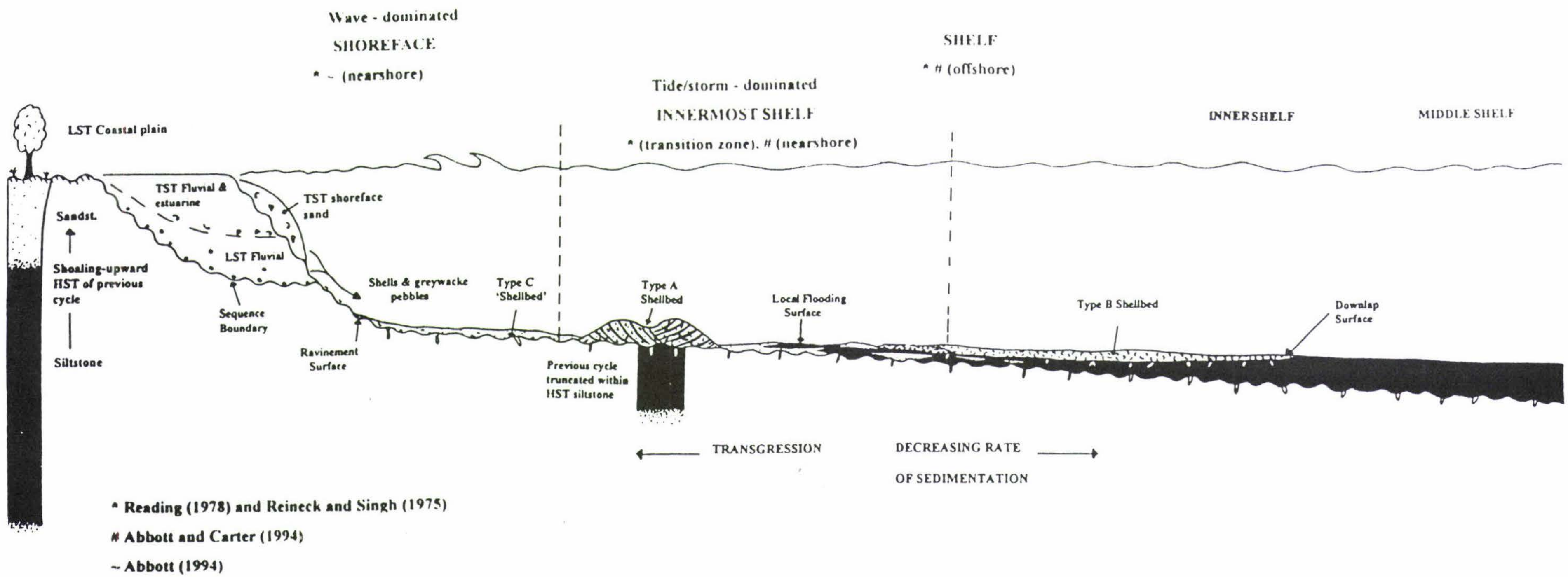


Figure 2.1.4 Diagram showing shelf environments (after Abbott, 1994), development of sequence boundaries, systems tracts and mid-cycle shellbeds, during a relative sea-level rise and subsequent fall (after Abbott and Carter, 1994).

2.1.4 Classification of Facies

In this thesis, facies are defined on the basis of composition, texture, sedimentary structures, macrofossil content and amount of bioturbation. Definition of facies is based on the classification of Abbott and Carter (1994) and the specific nomenclature used is that of Abbott (1994). Not all the facies that Abbott described at the Castlecliff section were recognised in Turakina Valley and some facies, although similar, did not fit well into Abbott's classification [**Table 2.1.1**]. Abbott (1994) describes 17 facies (based on the work of Abbott and Carter, 1994), which he grouped into 4 associations, based on the parameters listed above.

The **Sandstone Association** is divided into two sub - associations, **Well - sorted Sand** and **Silty Sandstone Sub - Associations**. The five facies within these sub - associations are generally deposited in shoreface - innermost shelf environments. In the Turakina valley sequence, the **Heterolithic Association** is made up of four facies, comprising shell conglomerate, laminated fine sand and silt and similar facies dominated by volcanic deposits. Heterolithic deposits are interpreted to accumulate on a tide/storm dominated innermost shelf (Abbott, 1994).

At Castlecliff the **Condensed Shellbed Association** is made up of 5 facies based largely on diagnostic macrofossil assemblages. In Turakina Valley these shellbeds are quite different in form from each other and can not so easily be distinguished by their macrofossil assemblages. These Type B shellbeds have therefore been divided into four facies based on their form or appearance. Facies of the Condensed Shellbed Association are generally deposited on a sediment starved inner shelf.

The **Siltstone Association** is divided into two sub - associations; **Laminated Siltstone Sub - Association** and **Massive Siltstone Sub - Association**. Three facies of the Siltstone Association were observed in the Turakina Valley section and these facies depict deposition on the inner and inner - middle shelf. Abbott's facies classification, modified for the Turakina Valley sequence, is summarised in **Table 2.1.1**.

2.1.4a Sandstone Association

A) Well - sorted Sand Sub - Association :-

- Facies TWS-1

This facies, as described by Abbott (1994) at Castlecliff (Facies WS-1) is composed of a cross-bedded shell conglomerate, dominated by *Paphies subtriangulata*. In Turakina Valley this facies is unfossiliferous and is made up of a planar and trough cross-bedded fine - medium sand e.g. Okehu Shell Grit at S22/129322 **(Plate 2.2.6)**.

- Facies WS-2

In Abbott's Castlecliff classification, Facies WS-2 consists of well - sorted, sparsely fossiliferous, fine sand. Sedimentary structures are generally not well expressed, possibly due to bioturbation, although poorly preserved parallel lamination and megaripple cross - bedding may occur. Mud flasers occur but are rarely preserved. Syn-depositional dm-scale convolute structures are also a feature of this type of facies. Faunal assemblages are dominated by *Paphies subtriangulata* which are restricted to thin lags. In the Turakina Valley sequence, sedimentary structures are similar to those described above but are generally better preserved (e.g. Kaikokopu Shell Grit at S22/069318, **Plate 2.2.21** and S22/072306, **Plate 2.2.22**). The occurrence of thin mud lamellae is much more prevalent compared to Facies WS-2 at Castlecliff, and probably indicates less turbulent conditions more suited to the preservation of flaser to wavy bedded structures. Bioturbation and convolute bedding was not observed within Facies WS-2 in Turakina Valley but the presence of fauna was most likely due to reworking and concentration into shell lags by storm waves. The dominant faunal species is *Paphies n. sp.* The occurrence of cross-bedding within this facies probably indicates periodic tidal influence. Facies WS-2 is indicative of deposition on a wave - dominated shoreface.

- Facies WS-3

At the Castlecliff section, Facies WS-3 has a higher silt content than WS-2 but is otherwise similar. Deposits are commonly intensely bioturbated and burrowed and primary bedding planes (almost exclusively parallel - lamellae) are therefore rarely preserved. Fauna is sparse and scattered and assemblages are dominated by *Paphies sp*, with *Zethalia* and/or *Fellaster* occurring as co-dominant species. Other fauna commonly present include estuarine bivalves such as *Austrovenus stutchburyi*, *Mactra tristis*, *Spisula aeqilatosa*, *Dosinia anus* and *Dosinia subrosea*. Subtidal fauna such as *Tiostrea*, *Purpurocardia* and *Chlamys gemmulata* may also occur. In the Turakina Valley sequence, only one example of this facies was observed (base of the Seafield Sand at S22/066315, **Plate 2.2.30**). At this location, Facies WS-3 has a much higher faunal content compared to the Castlecliff section, perhaps indicating a deeper, lower energy environment. The faunal assemblage is dominated by *Dosinia sp.*, *Myadora striata*, *Purpurocardia purpurata*, *Tawera spissa*, *Antisolarium egenum*, *Maoricolpus roseus*. Other prominent species include *Scalpomactra scalpellum*, *Tiostrea chilensis lutaria*, and *Poirieria zelandica*. A complete faunal list is included in **Table 2.2.5** (samples f 141 and 142a). Facies WS-3 represents deposition on a wave - dominated shoreface, seaward of Facies WS-2 (Abbott, 1994).

B) Silty Sandstone Sub - Association :-

- Facies ZS-1

Facies ZS-1, described by Abbott at the Castlecliff section, was not observed within the Turakina Valley sequence.

- Facies ZS-2

At the Castlecliff section Facies ZS-2 consists of very fine silty sandstone where fauna are generally scattered throughout the deposit and articulated valves are common. Faunal assemblages are dominated by more offshore taxa, for example *Serratina*, *Zenatia*, *Neilo*, *Antalis*, or *Tiostrea*, *Tawera*, *Chlamys* and *Maoricolpus*, indicating deposition within the shoreface - shelf transition zone (Abbott, 1994). In Turakina Valley it was difficult to distinguish between Facies ZS-1 and ZS-2 as described from the Castlecliff section, except for the more commonly scattered nature of the fauna within the deposits. The only example observed in Turakina Valley was the shellbed associated with the Shakespeare Cliff Sand at S23/031309 **(Plate 2.2.40)** The faunal assemblage includes relative abundances of *Myadora striata*, *Nucula nitidula*, *Pleuromeris zealandica*, *Purpurocardia purpurata*, *Scalpomactra scalpellum*, *Tawera spissa*, *Michrelenchus sanguineus*, *Xymene sp.* and *Zegalerus tenuis*. Other species such as *Carycorbula zelandica*, *Dosina sp.*, *Gari lineolata*, *Amalda sp.*, *Antisolarium egenum*, *Neoguraleus sp.*, *Sigapatella novaezelandiae* and *Stiracolpus sp.*, are sub - dominant within the assemblage **(Appendix E)**. The presence of *Gari*, *Antisolarium*, *Myadora* and *Scalpomactra* suggests deposition in a sandy innermost shelf environment. A complete faunal list is included in **Table 2.2.8** sample f 161b).

2.1.4b <u>Heterolithic Facies Association</u>

- Facies HE-1 (*Mactra tristis* shell conglomerate)

Facies HE-1 consists of large - scale cross - bedded, pebbly, shell conglomerate, often with intermittent mud drape structures which tend to be massive or more commonly wavy-bedded and streaky-laminated. Mega-flaser structures within the cross-bedded unit, often follow bedding planes and faunal assemblages are dominated by transported taxa such as *Mactra tristis* (estuarine) and *Paphies subtriangulata* (shoreface). Facies HE-1 is interpreted to form on a tide/storm dominated innermost shelf (Lewis, 1979) in conditions where mud is readily available. In a muddy, inner shelf environment, heterolithic alteration may result from fluctuating energy conditions e.g. varying between storm - dominated and tide - dominated, or delta - front settings. Shell material is presumably derived from contemporary cliff erosion and paralic environments. Greywacke pebbles were probably derived from erosion of the lowstand coastal plain fluvial facies, or from contemporaneous fluvial input (Abbott, 1994). Cross-bedded shell conglomerates most likely result from migration of dune-shaped bedforms (megaripple structures).

In the Turakina Valley sequence, Facies HE-1 was recognised as the basal member of several depositional sequences. The most striking example is the Kaikokopu Shell Grit at S22/089323 **(Plates 2.2.17, 2.2.18)** and S22/086331 **(Plate 2.2.19)**. Faunal assemblages are dominated by *Pleuromeris zealandica*, *Tiostrea chilensis lutaria*, *Amalda sp.*, and *Maoricolpus roseus*. Co-dominant species include *Glycymeris modesta*, *Paphies n. sp.*, *Purpurocardia purpurata*, *Talochlamys gemmulata*, *Tawera spissa*, *Leucotina ambigua*, *Trochus tiaratus*, *Xymene sp.*, *Zegalerus tenuis*, *Zethalia zelandica* and the Scaphopod, *Antalis nana*. *Maorimactra n. sp.* occurs as a sub-dominant species. The presence of *Pleuromeris*, *Tiostrea*, *Maoricolpus*, *Purpurocardia* and *Tawera* are more commonly associated with Type B Shellbeds and therefore most likely indicate deposition just landward of the inner shelf (i.e. innermost shelf).

- Facies HE-2 and HE-3

Facies HE-2 and HE-3 include small - scale heterolithic structures ranging from streaky - laminated siltstone to ripple - cross laminated fine sand with mud flasers. Facies HE-2 has a dominance of sand or coarse silt, while Facies HE-3 has a dominance of silt. Sedimentary structures characteristically found within Facies HE-2 are, flaser-bedding, ripple cross-lamination with flasers and less commonly, parallel-lamination. Sand horizons in this facies, commonly display symmetrical ripples and small-scale herringbone cross-bedding (Abbott, 1994). Symmetrical ripples most likely indicate wave influence. Facies HE-3 is dominated by mud-rich structures, mainly streaky-lamellae and lenticular-bedding, and less commonly by massive siltstone (Abbott, 1994). Both facies are commonly barren of macrofossils although sparsely scattered burrows may be evident. Like Facies HE-1, the depositional environment is on the tide/storm dominated innermost shelf.

In the Turakina Valley sequence, Facies HE-2 and HE-3 are fairly common. The majority of the Kaimatira Pumice Sand is made up of these facies in Turakina Valley.

This formation is well exposed 1 km up valley from the end of Morgans Road near S22/090310 **(Plate 2.2.10)**.

- Facies HE-4 (This is equivalent to Abbott's Facies HE-5)

The occurrence of Facies HE-4 is restricted to the basal member of the Kaimatira Pumice Sand and Kupe Formation and is found in the same position as Facies HE-1 at the base of a depositional sequence. Facies HE-4 is made up dominantly of volcaniclastic material which is often trough cross-bedded **(Plate 2.2.9)**. Intermittent mud drapes are a common feature, indicating an environment where tides had a strong influence on deposition. In Turakina Valley, large-scale herringbone cross-bedding was also observed, again suggesting tidal influence.

2.1.4c <u>Condensed Shellbed Association</u>

Facies of the Condensed Shellbed Association correspond to the mid-cycle shellbed within a depositional sequence **[Figure 2.1.3]**. Abbott (1994) divided this association into five facies, based largely on diagnostic fossil assemblages. In the Turakina Valley sequence the mid cycle shellbeds observed were classified on the basis of form (appearance) rather than solely on faunal assemblages. Faunal assemblages show a high occurrence of *Pleuromeris zealandica*, *Purpurocardia purpurata*, *Tawera spissa*, *Tiostrea chilensis lutaria* and *Maoricolpus roseus* **(Appendix E)**. The presence of *Carycorbula zelandica*, *Felaniella zelandica*, *Scalpomactra scalpellum*, *Amalda sp.*, *Sigapatella novaezelandiae* and *Waltonia inconspicua* is also significant. Large, conspicuous species such as *Tucetona*, *Atrina* and *Pecten* are also commonly associated with this type of mid-cycle shellbed. The assemblage is indicative of deposition on a sediment starved inner shelf environment (Abbott, 1994) **[Figure 2.1.4]** and starvation is thought to be caused by rapid deepening as the depocentre moves landward. Like mid-cycle shellbeds at Castlecliff, the mid-cycle shellbeds in the Turakina Valley sequence consist of diverse, well preserved *in situ* - near *situ* fauna in a muddy coarse silt - fine silty sand matrix, where articulated pairs are common. The mid-cycle shellbed is also referred to as a Type B Shellbed (see section 2.1.5) **[Figure 2.1.3 and 2.1.4]**.

- Facies TCS-1

Facies TCS-1 often has a pebbly shell conglomerate at its base **(Plate 2.2.31)**. The fauna within the conglomerate are generally very abraded and the unit is interpreted to have been transported to a position along the innermost shelf or beyond, possibly infilling a scour channel. A Type B Shellbed either overlying the conglomerate or making up the shellbed generally has quite a high pebbly content and the fauna are abundantly scattered throughout the unit in a muddy, silty-sand matrix **(Plates 2.2.31, 2.2.23 and 2.2.24)**. Entire faunal lists are included in **Table 2.2.3 and 2.2.6**.

- Facies TCS-2

Facies TCS-2 is a thin shellbed (no more than 50 cm thick) which often has a c. 1 m burrowing zone associated with it. The lower contact is undulating with dm-scale relief, indicating an erosional surface **(Plates 2.2.32 and 2.2.33)**. The matrix is composed of muddy, fine, silty sand and fauna are closely packed. Complete faunal lists are included in **Table 2.2.7**.

- Facies TCS-3

This facies type is easily distinguished by its appearance. The shellbed is composed of two parts. The lower half of the shellbed is dominated by smaller while the upper half is dominated by closely packed larger fauna and the matrix in both cases is made up of muddy, fine sand **(Plates 2.2.35, 2.2.36 and 2.2.38)**. The presence of *Neothyris sp.* appears to be restricted to this facies type in the upper half of the shellbed. Complete faunal lists are included in **Table 2.2.8**.

- Facies TCS-4

Facies TCS-4 is a Type B Shellbed consisting of abundant, diverse fauna, evenly distributed throughout the shellbed **(Plate 2.2.41)**. The matrix is made up of a muddy, fine sand. The occurrence of the bivalve *Divariella huttoiona* appears to be restricted to this shellbed. A complete faunal list is included in **Table 2.2.10**.

Interpretation of these shellbeds is dicussed in relevant sections in Chapter Two, Part II and in Chapter Three.

2.1.4d Siltstone Association

Facies of this association dominate the sequence in Turakina Valley. Abbott subdivided the Siltstone Association into two sub - associations, each consisting of two facies. Only three of the four Siltstone Association facies, described by Abbott from the Castlecliff section, were observed in Turakina Valley.

A) Bedded Siltstone Sub - Association :-

Preservation of primary sedimentary structures in this sub - association indicates suppression of bioturbating organisms which may be due to high sedimentation rate and turbidity, combined with a very fine grained substrate (Abbott, 1994).

- Facies BZ-1

Facies BZ-1 was not observed within the Turakina Valley sequence.

- Facies BZ-2

Facies BZ-2 includes cm-dm interbedded, streaky laminated and bioturbated siltstone. This facies is characterised by very fine - grained silt, and lignite flecks commonly leave brownish streaks on scraped surfaces. The presence of fauna is rare (e.g. Lower Okehu Siltstone at S22/091362, **Plate 2.2.5**).

B) Massive Siltstone Sub - Association :-

This sub - association is distinguished by its massive rather than bedded appearance and is interpreted to form in an inner - middle shelf environment where primary bedding was obliterated by bioturbating organisms which possibly reflects lower accumulation rates.

- Facies MZ-1

At Castlecliff Facies MZ-1 consists of massive, intensely bioturbated, sparsely fossiliferous, fine, sandy siltstone. Fauna are generally well preserved and scattered and small clumps of *Atrina* or *Tiostrea* may be present. Other characteristic fauna include, *Myadora kaiiwiensis?, Neilo australis, Zenatia acinaces* and *Echinocardium sp.*. In Turakina Valley only one example of Facies MZ-1 was observed at the base of the Karaka Siltstone **(Plate 2.2.41)**. Here fauna are quite abundantly scattered in a fine sandy matrix which may account for the greater occurrence of faunal activity compared to Facies MZ-1 at Castlecliff. A short faunal list is included in **Table 2.2.11**.

- Facies MZ-2

Facies MZ-2 is made up of massive, sparsely fossiliferous - barren siltstone and is generally finer grained than Facies MZ-1. This facies will often display cracking patterns when weathered which is attributed to its high clay content. Flecks of lignite may also occur. When present, the faunal assemblage is dominated by sparsely scattered *Stiracolpus* species. The Upper Westmere Siltstone in Turakina is largely made up of this type of facies (**Plate 2.2.25**).

Association and Facies		Descriptions	Example from Turakina Valley	Plate	Interpretation
Massive	MZ-2	Massive siltstone. Barren to sparsely fossiliferous.	Upper Westmere Siltstone, Shakespeare Cliff Siltstone	2.2.25 2.2.38	Inner - middle shelf
Siltstone	MZ-1	Massive, fine-sandy siltstone. Sparsely fossiliferous.	Karaka Siltstone	2.2.41	Inner - middle shelf
Laminated	BZ-2	Cm-dm interbedded streaky-laminated and bioturbated siltstone. Rare fossils.	Lower Okehu Siltstone, Lower Castlecliff Siltstone	2.2.5 2.2.34	Inner shelf
	TCS-4	Muddy, fine sand with abundant, diverse fauna evenly distributed throughout the shellbed. Bivalve *Divariella huttoiona* is distinctive to this shellbed. See section 2.1.4c for list of dominant fauna.	Upper Castlecliff Shellbed	2.2.41	Sediment starved inner shelf
	TCS-3	Shellbed divided into two parts both of which have a muddy, fine sandy matrix. The lower part is dominated by smaller fauna while the upper half consists of tightly - packed larger fauna. Presence of *Neothyris sp.* is distinctive. See section 2.1.4c for a list of dominant faunal species.	Tainui Shellbed	2.2.35 2.2.36 2.2.38	Sediment starved inner shelf
Condensed Shellbed	TCS-2	Thin shellbed with abundant, diverse fauna in a muddy fine silty sand matrix. Lower contact undulating to dm-scale, and a c. 1 m burrowing zone occurs below this contact. See section 2.1.4c for list of dominant faunal species.	Lower Castlecliff Shellbed	2.2.32 2.2.33	Sediment starved inner shelf
	TCS-1	Basal fossiliferous conglomerate may be present. If present, this conglomerate is overlain by a muddy, silty sand with abundant scattered fauna. This facies may also occur as a pebbly, muddy, silty sand with abundant, diverse fauna. See section 2.1.4c for list of dominant faunal species.	Morgans Shellbed, Howie Shellbed	2.2.23 2.2.24 2.2.31	Innermost shelf
	HE-4	Poorly - sorted pumiceous sand with trough cross-bedding and frequent mud drapes.	Kaimatira Pumice Sand	2.2.9	Tide/storm dominated innermost shelf
Heterolithic	HE-3	Small-scale heterolithic facies dominated by mud - rich structures; mainly streaky lamination, lenticular-bedded and massive siltstone. Rarely fossiliferous.	Kaimatira Pumice Sand, Lower Okehu Siltstone Seafield Sand	2.2.10 2.2.2 2.2.29	Tide/storm dominated innermost shelf
	HE-2	Small-scale heterolithic facies dominated by fine sand - coarse silt rich structures; mainly flaser-bedding, ripple cross-lamination with flasers, parallel-lamination. Rarely fossiliferous.	Kaimatira Pumice Sand, Lower Okehu Siltstone, Upper Okehu Siltstone, Ruakina Formation	2.2.10 2.2.3 & 4 2.2.7 2.2.21	Tide/storm dominated innermost shelf
	HE-1	Large-scale cross-bedded shell - pebble conglomerate with mud drapes. Mega-flasers may exist along foreset bedding planes.	Kaikokopu Shell Grit, Makuhou Shell Conglmerate Okehu Shell Grit	2.2.17 & 2.2.19 2.2.13 2.2.5	Tide/storm dominated innermost shelf
Silty	ZS-2	Massive, silty fine sandstone with abundant scattered fossils.	Shakespeare Cliff Sand (associated shellbed)	2.2.40	Shoreface-shelf transition
Sandstone	WS-3	Intensely burrowed and bioturbated, shelly, slightly silty fine sand.	Seafield Sand (associated, lowermost shellbed)	2.2.30	Wave-dominated shoreface
Well-sorted	WS-2	Well-sorted fine sand with parallel lamination, trough cross-bedding and rare shelly lags	Kaikokopu Shell Grit, Pinnacle Sand	2.2.22 2.2.35	Wave-dominated shoreface
	TWS-1	Large-scale, planar cross-bedded fine - medium sand. Unfossiliferous.	Okehu Shell Grit	2.2.6	Tide/storm dominated innermost shelf

Table 2.1.1 Facies observed within the Turakina Valley sequence (based on the facies classification of Abbott, 1994).

Footnote: T infront of WS and CS facies refers to facies seen only in Turakina Valley

2.1.5 Classification of Shellbeds

The nomenclature used for classification of shellbeds in Turakina Valley is that of Abbott and Carter (1994) **[Table 2.1.2]**. A **Type A1 Shellbed** consists dominantly of Facies HE-1; coarse sand and shell gravel with transported fauna and is indicative of deposition on a tide/storm dominated innermost shelf. The faunal assemblage in Turakina Valley is dominated by *Glycymeris modesta, Paphies n. sp., Pleuromeris zealandica, purpurocardia purpurata, Talochlamys gemmulata, Tawera spissa, Tiostrea chilensis lutaria, Amalda sp., Leucotina ambigua*, and *Maoricolpus roseus*. The occurrence of *Maorimactra n. sp.* is also common **(Appendix E)**. *Paphies n. sp.* and *Maorimactra n. sp.* seem to indicate transportation from the shoreface area while the other fauna are more indicative of innermost - inner shelf conditions.

A **Type A2 Shellbed** comprises sand and silty sand facies, including *in situ* and near *situ* fauna. In the Turakina Valley section, the Type A2 Shellbed is not restricted to one facies type but encompasses Facies WS-2, WS-3 and ZS-2, and therefore it was not possible to establish a diagnostic faunal assemblage.

Both Type A Shellbeds indicate deposition at the beginning of a transgressive phase when wave and tidal currents strongly influence sedimentation.

Type B Shellbeds are made up of fine sand, and silty sand with abundant *in situ* and near *situ* fauna and usually occur in the mid - cycle position within a sequence. This type of shellbed represents deposition on a sediment starved inner shelf near the time of maximum flooding by the sea. In the Turakina Valley sequence, the faunal assemblages are dominated by the occurrence of *Carycorbula zelandica, Chlamys gemmulata, Pecten sp., Pleuromeris zealandica, Purpurocardia purpurata, Tawera spissa, Tiostrea chilensis lutaria, Amalda sp., Austrofusus glans, Maoricolpus roseus, Sigapatella novaezelandiae, Trochus tiaratus, Zegalerus tenuis* and *Waltonia inconspicua* **(Appendix E)**. Type B Shellbeds are restricted to facies that make up the Condensed Shellbed Association.

A **Type C Shellbed** occurs at the sequence boundary where a wave - planed surface is bored by intertidal *in situ* fauna; commonly *Anchomasa (Barnea) similis*.

Shellbed	Characteristic Species	Fabric	Matrix	Environment	Systems Tract	Examples: Turakina Valley
Type A1	Largely reworked fauna, such as *Paphies n. sp., Maorimactra n. sp., Glycymeris, Pleuromeris, Purpurocardia, Tawera, Talochlamys, Tiostrea, Maoricolpus, Leucotina, Amalda sp.* commonly present	Transported	Coarse sand and shell gravel	Tide/storm dominated innermost shelf	Transgressive	Kaikokopu Shell Grit
Type A2	Intertidal and shallow sub-tidal species: varies with facies type	*In situ* and near *situ*	Fine sand and silty sand	Wave dominated shoreface	Transgressive	Base of Seafield Sand, Shakespeare Cliff Sand
Type B	Soft bottom species: *Caryocorbula, Chlamys, Pecten, Pleuromeris, Purpurocardia, Tawera, Tiostrea, Amalda, Austrofusus, Maoricolpus, Sigapatella, Trochus, Zegalerus, Waltonia*	*In situ* and near *situ*	fine sand and silty sand	Sediment starved inner shelf	Mid-cycle Shellbed	Tainui Shellbed
Type C	*Anchomasa (Barnea) similis*	*In situ* - Borings	Siltstone	Intertidal rock platform	Sequence boundary	Top of Lower Westmere Siltstone

Table 2.1.2 : Major shellbed types distinguished within the ten depositional sequences in Turakina Valley (After Abbott and Carter, 1994 and Abbott, 1994).

2.1.6 Pecten Zones in Pleistocene Wanganui Basin Formations

The macrofossil *Pecten* is of great importance as an index fossil worldwide and is commonly used for correlation purposes. In New Zealand, *Pecten* has not been found in deposits older than the Castlecliffian Stage (mid-Pleistocene age). Across the onland Wanganui Basin section, *Pecten* has been of great value in establishing stratigraphic constraints. Fleming (1957) found that there were consistent zones across the basin of different subspecies of *Pecten* related to progressive evolution of the species **[Figure 2.1.5]**.

The different *Pecten* subspecies are restricted to particular formations within the Pleistocene sequence and therefore aid to some extent in identification and correlation of formations across the basin **[Figure 2.1.6]**. In this thesis some minor variations to Fleming's work have been noted in Turakina Valley. These differences are discussed in detail in the relevant depositional sequence section in Part II of this chapter and in the discussion in Chapter Three. In Turakina Valley, the First Appearance Datum (FAD) of *Pecten* occurs in the Ruakina Formation (Waikopiroensis Zone of Fleming, 1957) which correlates with the Upper Westmere Siltstone at Castlecliff.

Caution should be exercised when using *Pecten* as an index fossil as difficulties may occur in differentiating between some subspecies. Also, zone boundaries are time-transgressive and more than one index *Pecten* may occur in the same horizon, as observed within the Tainui Shellbed in the Turakina Valley sequence.

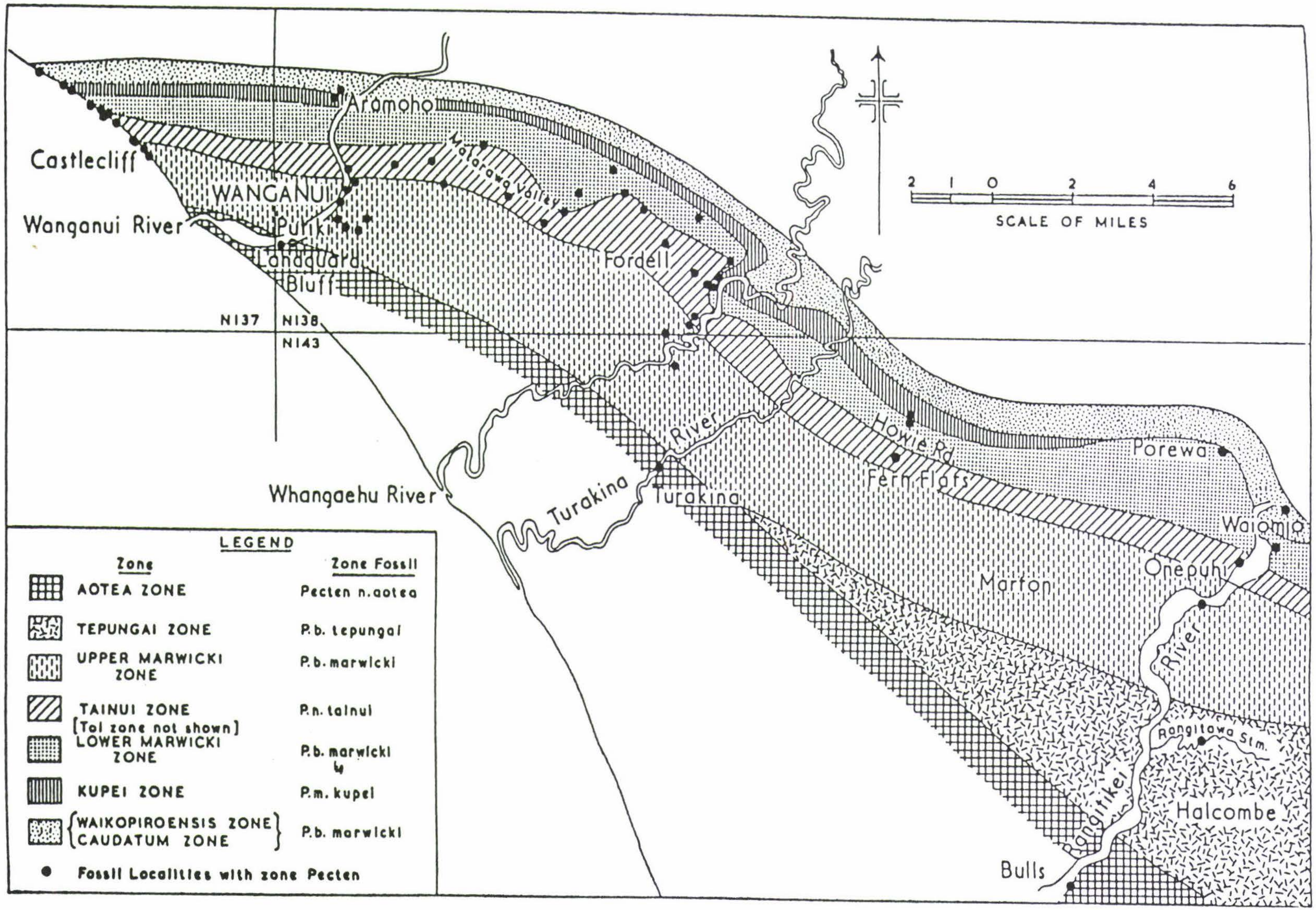


Figure 2.1.5 *Pecten* zones within the onland Wanganui Basin sequence from Wanganui to Rangitikei Valley (Fleming, 1957).

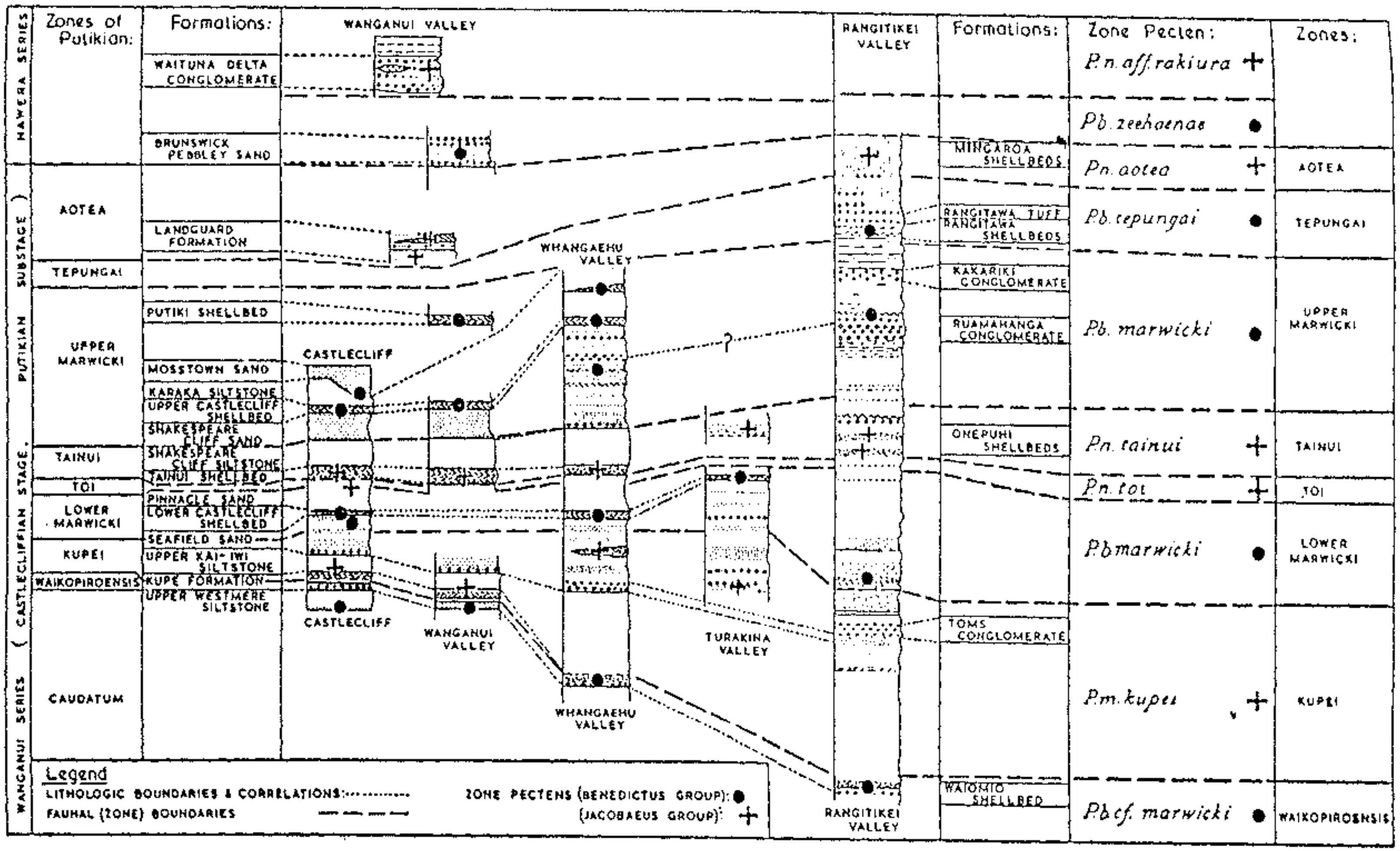


Figure 2.1.6 Diagram showing correlation of *Pecten* zones in the Wanganui Basin onland sequence (Fleming, 1957).

PART II

2.2.1 Format of Part II

2.2.2 - 2.2.11 Formal Description and Interpretation of Formations that make up Depositional Sequences 1 - 10

2.2.1 Format of Part II

This section of chapter two is made up of a detailed description of each formation observed within the study area and each formation is part of one of ten depositional sequences recognised within the Plio-Pleistocene sequence. Aside from section 2.2.2 (Depositional Sequence 1 which was not directly observed), each section includes the following information:

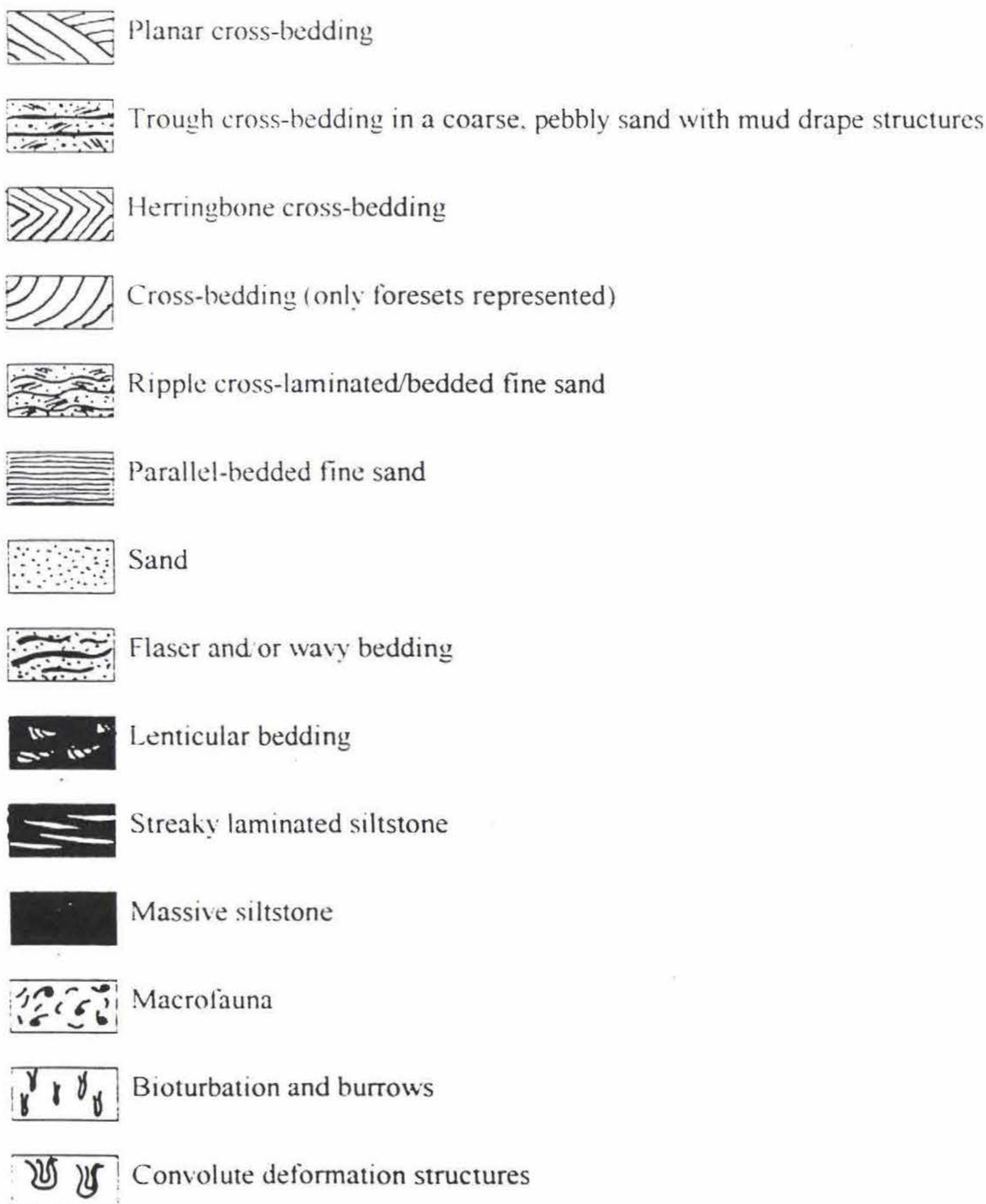
1) Location of the type section
2) Details about where the name of the formation originated from
3) The thickness of the formation (field measurements and altimeter readings (**Appendix D**))
4) A Reference Section (RS) for Turakina Valley
5) Descriptive Sections (DS) in Turakina Valley
6) A detailed description of the reference section and descriptive sections
7) Description of the palaeontology where present. A list of macrofauna is included at the end of each section. The occurrence of individual faunal species within Type A1 and Type B Shellbeds is included in **Appendix E** and the results are discussed in Chapter Three.
8) Paleocurrent data (if collected), presented as a rose diagram (s). The actual data can be found in **Appendix C**.
9) An interpretation of the overall facies architecture
10) Age of the formation and correlation to both the Castlecliff section and to Rangitikei Valley. A correlation diagram is included in Chapter Three.

Where collected, tephra analysis data (**Appendix A**) and grain size analysis data (**Appendix B**) is included in the descriptions section for each formation. The grain size analysis data focuses only on the dominant grain size and the degree of sorting of a given sand deposit, in an effort to check the accuracy of field observations.

At the end of each section, a summary stratigraphic column of the depositional sequence is included. Here the abbreviation 'DS' stands for Depositional Sequence.

Each diagram includes a representative sketch of the formations within a given depositional sequence. A brief description of the units present is included and an interpretation of environment of deposition and sequence stratigraphy. All these summary columns together make up the representative stratigraphic column for lower Turakina Valley which is presented in Chapter Three. A map and cross section showing the distribution of each depositional sequence can be found at the back of this thesis.

Key to symbols used in summary stratigraphic diagrams:



2.2.2 Depositional Sequence 1

Within the study area the formation (i.e. Butlers Shell Conglomerate) of Depositional Sequence 1, as defined by Abbott (1994), was not observed. The sequence is present north of the study area past the intersection of Turakina Valley Road and Taurimu Road. At Grid Reference S22/115346, a cliff face between Makuhou Road and Taurimu Road, the Butlers Shell Conglomerate is most likely obscured by slump material. The Upper Maxwell Formation (Fleming, 1953) of Nukumaruan age, was clearly identified by characteristic non - marine sediments (including a prominent lignite band) at Grid Reference S22/128341 - 138343, a site between the above mentioned cliff face and Galpins Road. Other formations in the Maxwell Group also display non - marine sediments (Fleming, 1953) but the non - marine sediments observed at S22/128341 were the first encountered below a thick sequence of siltstone, presumably the Lower Okehu Siltstone. The Butlers Shell Conglomerate must therefore lie somewhere between the cliff face and site S22/128341. The estimated position of Depositional Sequence 1 is included on the map and cross section in the back envelope of this thesis.

The unconformity between the Butlers Shell Conglomerate and Upper Maxwell Formation is thought to represent the base of the Jaramillo Subchron (Turner and Kamp, 1990; Pillans *et al*, 1994). The work of Turner and Kamp (1990) was based on DSDP Site 552A of Shackleton and Hall (1984), who attributed an age of 0.98 Ma to the base of the Jaramillo Subchron. Pillans *et al* (1994) based their interpretation on ODP Site 677 of Shackleton *et al* (1990) who attributed an age of 1.07 Ma to the base of the Jaramillo Subchron.

2.2.3 Depositional Sequence 2

Makuhou Reserve Formation (New)

Type Section : Turakina Valley at S22/118324; an outcrop on Makuhou Road beginning at the Makuhou Reserve sign and following the road eastwards to the top of the hill.

Name : named by the writer after Makuhou Reserve in Turakina Valley.

Thickness : 18 m of the formation is exposed along Makuhou Road

Descriptive Section : S22/115346 - 116343 Cliff face exposed due to large slip between Makuhou Road and Taurimu Road.

Descriptions

At the type section near the Makuhou Reserve sign on Makuhou Road, the base of the outcrop consists of 1 m of faintly planar cross - bedded sand with mud flasers, which become more prominent up - section (Facies WS-2). The upper contact is fairly erosive with cm - scale relief. Overlying the contact, approximately 18 m of intensely bioturbated, massive, dm-bedded and streaky-laminated muddy silt occurs (Facies HE-3). Convolute deformation structures are a common feature **[Plate 2.2.1]**. The formation becomes increasingly sandy up - section **[Plate 2.2.2]**; the uppermost unit resembling heterolithic facies in that it has ripple cross-laminated coarse silt **(sample S 34, Appendix B)** with burrowed flaser and wavy bedding (Facies HE-2) **[Plate 2.2.3]**. This sequence is summarised in **Figure 2.2.1**.

The large cliff exposure at Descriptive Section (S22/115346) between Makuhou and Taurimu Roads, consists of up to 20 m of sediment of the Makuhou Reserve Formation. The lowermost 7 - 8 m is made up of laminated siltstone with occasional dm - scale massive beds. Rare, coarse, shelly sand lenses (up to 50 mm thick), resembling Facies HE-2 occur also. Above this bedded siltstone member, approximately 5 m of chaotically bedded, muddy siltstone occurs (Facies HE-3). Large, dm-bedded, convolute deformation structures are a prominent feature. Up to 2 m of laminated siltstone caps the outcrop **[Plate 2.2.4]**.

The distribution of Depositional Sequence 2 is shown on the map and cross section at the back of this thesis.

Palaeontology

Devoid of macrofossils except for rare shelly sand lenses.

Interpretation

The Makuhou Reserve Formation represents the TST for Depositional Sequence 2 in Turakina Valley.

Facies of the Makuhou Reserve Formation on Makuhou Road near the Makuhou Reserve sign indicate deposition on a tide - dominated innermost shelf (Facies HE-2 and HE-3). This formation most likely grades gradually into the massive Lower Okehu Siltstone. The thick sequence of small - scale heterolithic facies is unusual for a Wanganui - type TST and may indicate either uplift along the upper flank of the Marton Anticline, where uplift balanced sea-level rise, or a major sediment source was diverted into this part of the basin during relative sea-level rise causing a delta to form along the shelf margin (see section 3.2)

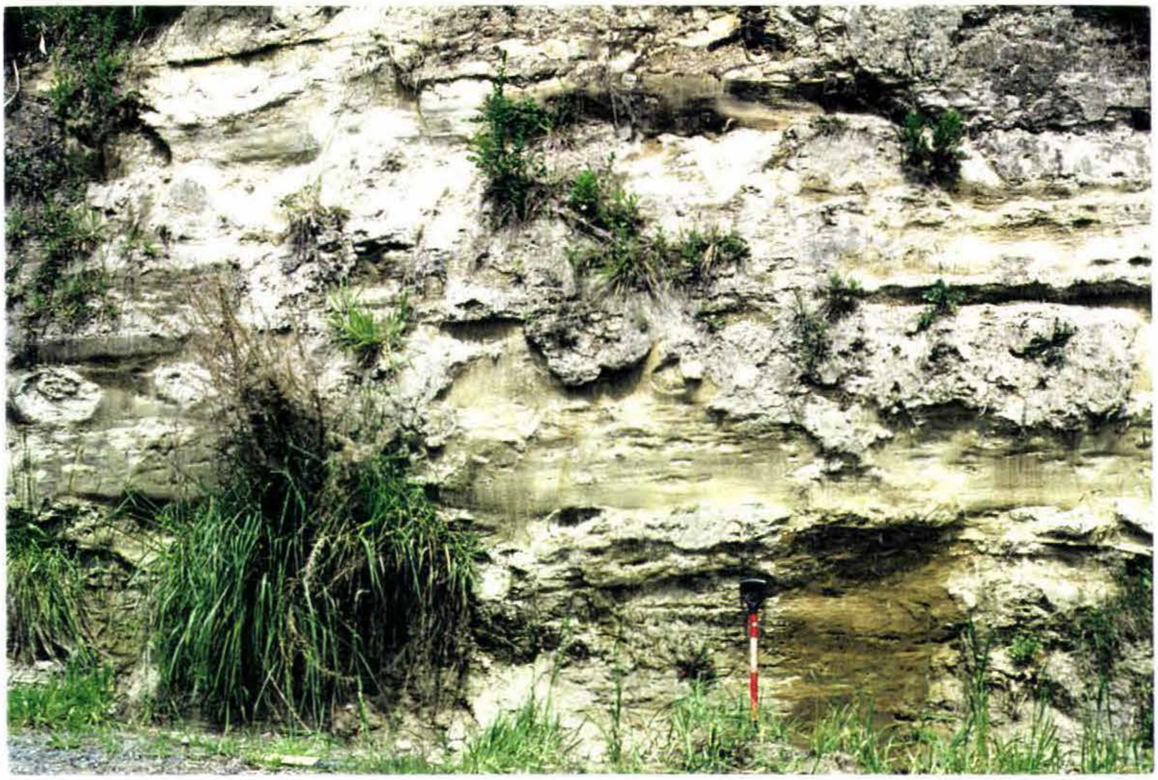
Age and Correlation

The base of the Makuhou Reserve Formation is equivalent to Abbott and Carter's (1994) Mowhanua Formation which consists of up to 2 m of cross-bedded shell gravel with mud flasers at the Castlecliff section. The formation is renamed for the Turakina sequence because of the large unit of heterolithic (TST) facies associated with it which has previously not been described elsewhere **(see Figure 3.1)**.

The Makuhou Reserve Formation is placed within Oxygen Isotope Stage 31 by the writer based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990 and Pillans, 1994). The formation is attributed an age of 1.05 - 1.1 based on the age of 1 Ma for the Potaka Pumice (Pillans *et al*, 1994). The Makuhou Reserve Formation lies within the Jaramillo Subchron (Turner and Kamp, 1990) (see **Figures 1.2**).

Plate 2.2.1 Makuhou Reserve Formation at S22/118324 on Makuhou Road near the Makuhou Reserve sign. At the base of the outcrop c. 1 m of faintly planar cross-bedded sand with mud flasers can be seen (Facies WS-2). A quite sharp contact (up to 0.1 m above the spade handle), divides this unit from the overlying c. 3 m of muddy dm-bedded and streaky-laminated siltstone with frequent convolute deformation structures (Facies HE-3).

Plate 2.2.2 Makuhou Reserve Formation at S22/118324 c. 30 m up the road from the Makuhou Reserve sign on Makuhou Road. Dm-scale, massive, burrowed siltstone beds (Facies HE-3), and small-scale ripple cross-beds with wavy bedding (Facies HE-2) make up the middle - upper part of the Makuhou Reserve Formation.



1 m

Plate 2.2.1

Convolute deformation

Burrowed, dm - bedded silt

Ripple cross-laminated fine sand

1 m

Plate 2.2.2

Plate 2.2.3 Makuhou Reserve Formation at S22/118324, and following the road eastwards from the Makuhou Reserve sign on Makuhou Road. The plate shows a close-up of small-scale ripple cross bedding with wavy bedding (Facies HE-2) within the middle - upper part of the Makuhou Reserve Formation (35 mm lens cap for scale).

Plate 2.2.4 Makuhou Reserve Formation at S22/115346, a cliff face between Makuhou Road and Taurimu Road. The lowermost 7-8 m consists of interbedded silt and sand, with occasional dm-scale, massive silt beds (Facies HE-2 and HE-3). Overlying this unit is c. 5 m of massive - dm-bedded, muddy siltstone with frequent convolute deformation structures. A 2 m unit consisting of small - scale heterolithic facies caps the outcrop.

Plate 2.2.3

Plate 2.2.4

Lower Okehu Siltstone

Type Section : Castlecliff section between the mouth of Ototoka Stream and south-east to the mouth of Kai-iwi Stream.

Name : named by Fleming (1947a) for an outcrop of the formation on the coast near the mouth of Okehu Stream.

Thickness : up to 12 m outcrops at two sites in Turakina Valley (this work). Abbott (1994) recorded a thickness of 45 m in Turakina Valley at different sites (on the Whangaehu side of the Turakina River).

Reference Section : S22/091362 - 093366 Turakina Valley Road - Taurimu Road intersection and down Turakina Valley Road just past a small bridge c. 500 m SW from the intersection.

Descriptive Section : S22/129322 Upper Makuhou Road

Descriptions

Only 12 m of the Lower Okehu Siltstone is exposed at the reference section where it consists of streaky - laminated to lenticular-bedded siltstone (Facies BZ-2). Infrequent shelly lenses up to 50 mm thick occur throughout the exposure. The upper part of the formation is seen at the small bridge along Turakina Valley Road, underlying a sharp contact with the Okehu Shell Grit (Depositional Sequence 3) **[Plate 2.2.5]**. The formation here also consists of Facies BZ-2.

Farther up Makuhou Road at S22/129322, approximately 3 - 4 m of the Lower Okehu Siltstone is exposed as a massive, blue-grey siltstone unit (Facies MZ-2) with an uppermost muddy layer, approximately 1 m thick. This muddy layer is truncated by the basal unit of the Okehu Shell Grit and the contact is bored **[see Plate 2.2.6]**. This section is summarised in **Figure 2.2.1** and the overall distribution of Depositional Sequence 2 is shown on the map and cross section at the end of this thesis.

Palaeontology

Shelly lenses observed within the exposed upper part of the formation are dominated by the bivalve *Maorimactra*. Shells are well preserved but mostly disarticulated.

Interpretation

The Lower Okehu Siltstone consists of the HST deposits of Depositional Sequence 2 in the Wanganui Basin Plio - Pleistocene sequence.

Facies seen at the Turakina Valley Road sites indicate deposition on the inner shelf in an environment where sedimentation rates were low enough to allow the preservation of primary bedding. In sequence stratigraphic terms, the sharp upper contact with the Okehu Shell Grit at DS(S22/091362) and DS(S22/129322) represents the sequence boundary between Depositional Sequence 2 and 3.

Age and Correlation

The Lower Okehu Siltstone is assigned to Oxygen Isotope Stage 29 (Shackleton *et al* 1990) and attributed an age of c. 1 Ma (Abbott and Carter 1994). The recent fission - track date for the Potaka Pumice (Pillans *et al* 1994), indicates a slightly older age for the Lower Okehu Siltstone and the formation is placed within Oxygen Isotope Stage 31 by the writer based on the work of Pillans (1994) (see **Figure 1.2**). The top of the formation marks the Matuyama/Jaramillo boundary (990 Ka, Abbott and Carter 1994; Pillans, 1994).

At the Castlecliff section, the Lower Okehu Siltstone consists of approximately 20 m of finely laminated, ripple - bedded and massive blue-grey siltstone, overlying a basal fossiliferous conglomerate (Fleming, 1953). Although not observed in the Turakina Valley (this work), the conglomerate, representing the TST for Depositional Sequence

2, is persistent across the basin to Rangitikei Valley (Abbott, 1994). The nature of the siltstone does not appear to change across the basin although the formation thickens from 20 m at the Castlecliff section, to 45 m in Turakina Valley (Abbott, 1994) and 50 m + in Rangitikei Valley (Abbott, 1994) (See **Figure 3.1**).

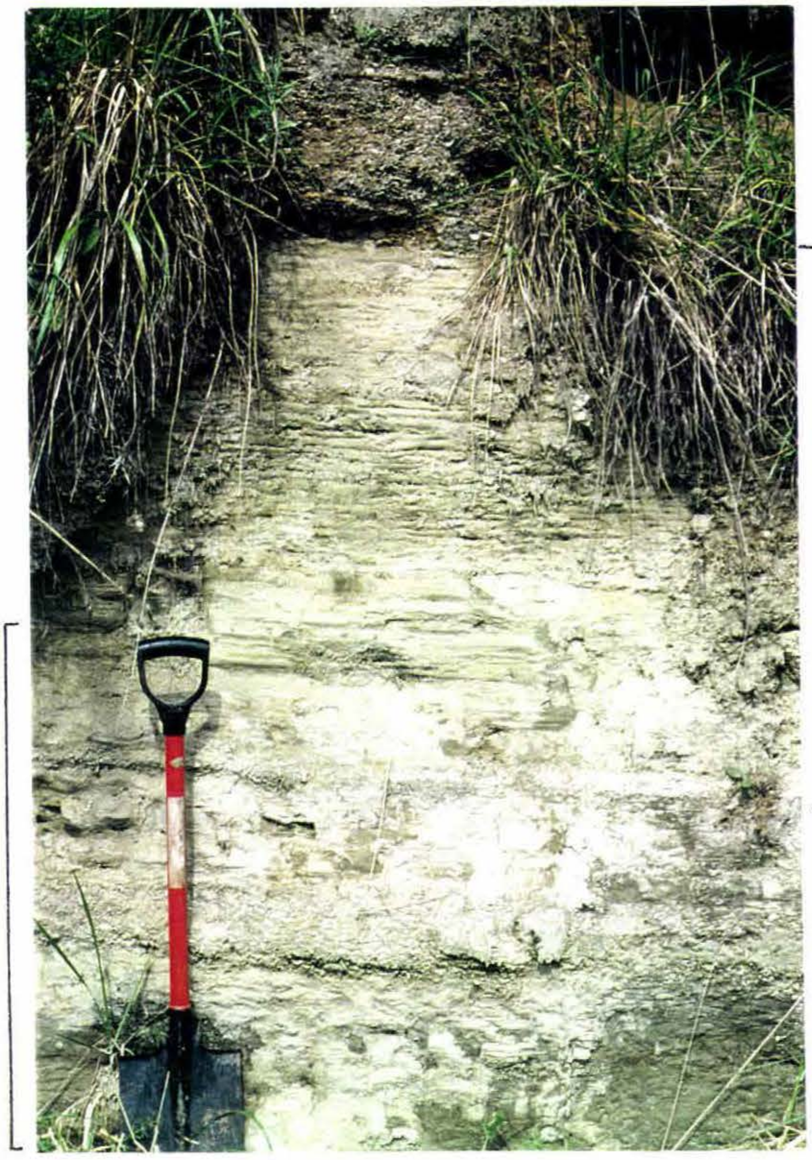


Plate 2.2.5 Lower Okehu Siltstone/Okehu Shell Grit contact at S22/091362 on Turakina Valley Road near a small bridge c. 500 m south-west of the intersection with Taurimu Road. The Lower Okehu Siltstone here is streaky-laminated with up to 50 mm thick bands of shelly material mainly composed of *Maorimactra* (Facies BZ-2). The contact with the Okehu Shell Grit is sharp with cm-scale relief and marks the sequence boundary between Depositional Sequence 2 and 3. Only the lowermost c. 0.4 m of the Okehu Shell Grit is visible in this plate and at this location it is made up of a pebbly shell conglomerate (Facies HE-1) with no obvious bedding structures.

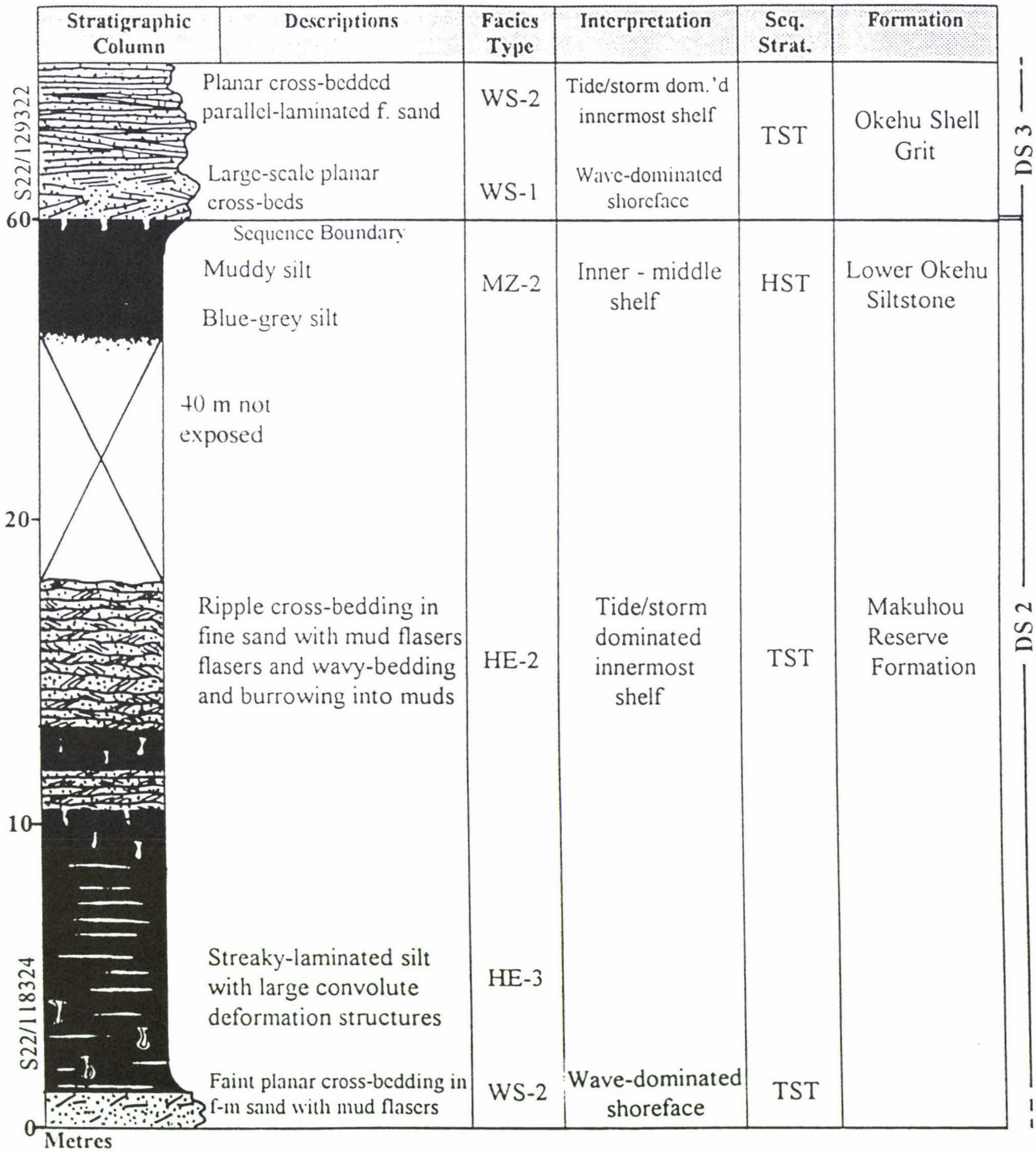


Figure 2.2.1 Stratigraphic summary diagram for Depositional Sequence 2 in Turakina Valley from sites along Makuhou Road. (See map and cross-section at the back of this thesis).

2.2.4 Depositional Sequence 3

Okehu Shell Grit

Type Section : Castlecliff section between the mouth of Ototoka Stream and south-east to the mouth of Kai-iwi Stream.

Name : named by Fleming (1953) for the shell grit layer between the Okehu Siltstone formations.

Thickness : up to 4 m in Turakina Valley.

Reference Section : S22/091362 Small bridge on Turakina Valley Road c. 500 m south of the intersection with Taurimu Road.

Descriptive Section : S22/129322 Upper Makuhou Road.

Descriptions

The Okehu Shell Grit at the reference section, consists of an unbedded, c. 0.4 m basal shell/pebble conglomerate (Facies HE-1, Type A1 Shellbed), overlying a laminated siltstone (Lower Okehu Siltstone) **[see Plate 2.2.5]**. Approximately 1.5 m of fine - medium, parallel-bedded sand with muddy wavy bedding and mud flasers (Facies HE-2) overlies the conglomerate. The outcrop then becomes obscured.

The base of the Okehu Shell Grit on Makuhou Road at DS (S22/129322), is marked by a sharp lower contact showing dm-scale relief and which has a bored surface (Type C shellbed). Overlying this contact is a moderately well-sorted, medium sand **(sample S35, Appendix B)**, which displays large-scale planar cross-bedding and is 0.8 - 1.0 m thick (Facies WS-1) **[Plate 2.2.6]**. This basal member grades into parallel-laminated and planar cross-bedded, well-sorted fine sand **(sample S36, Appendix B)**, and is 3-4 m thick (Facies WS-2) **[Plate 2.2.7]**. The silt component increases up-section and the contact with the overlying Upper Okehu Siltstone is gradational. This section is summarised in **Figure 2.2.3** and the overall distribution of Depositional Sequence 3 is shown on the map and cross - section at the end of this thesis.

Palaeontology

The fossiliferous, basal conglomerate at the reference section on Turakina Valley Road, consists of mainly transported macrofauna. A faunal collection was not made at this site.

Paleocurrent Data

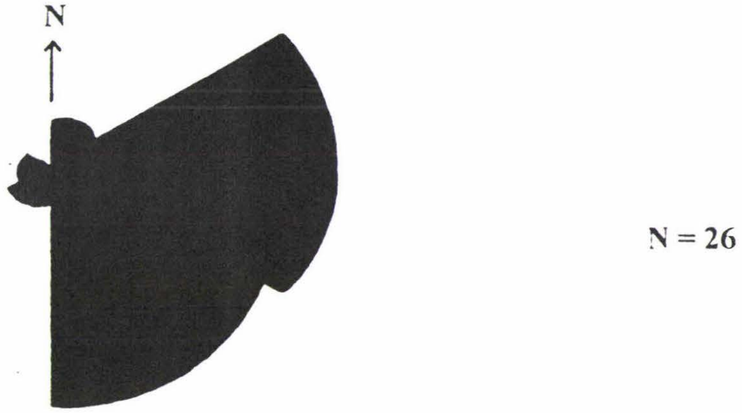


Figure 2.2.2 Rose diagram of paleocurrent data taken from the basal planar cross-bedded unit and predominantly from the overlying parallel-laminated and planar cross-bedded unit at the descriptive section on Makuhou Road (**Appendix C**). The data obtained indicates a broad unimodal current trending east and south-east, suggesting a longshore tidal influence.

Interpretation

The Okehu Shell Grit corresponds to the TST of Depositional Sequence 3 in the Turakina Valley Plio - Pleistocene sequence.

Facies at the reference section and at the Makuhou Road section indicate deposition on a tide/storm dominated innermost shelf and wave-dominated shoreface (section 2.1.4a). Paleocurrent data from Makuhou Road indicates that a strong south-easterly flowing wave-induced current and perhaps also a tidal current influenced deposition. The sharp lower contact marks the lower sequence boundary between Depositional Sequence 2 and 3. The upper contact is conformable with the Upper Okehu Siltstone.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 of Shackleton *et al* (1990), Abbott and Carter (1994) placed the Okehu Shell Grit within Oxygen Isotope Stage 27 and attributed an age of c. 990 Ka to the formation. The recent fission - track age of 1 Ma for the Potaka Pumice (Pillans *et al*, 1994) indicates an age slightly older than 1 Ma for the Okehu Shell Grit. The base of this formation marks the top of the Jaramillo Subchron (Turner and Kamp, 1990; Pillans *et al*, 1994). The Okehu Shell Grit is placed within Oxygen Isotope Stage 29 by the writer based on the work of Pillans (1994) (see **Figure 1.2**).

The Okehu Shell Grit thickness at the Castlecliff section varies from 0 - 8 m (Fleming, 1953) due to infilling of the ravinement surface of the Lower Okehu Siltstone. In Rangitikei Valley, the formation can be correlated with a conglomerate c. 40 m below the base of the Potaka Formation (Abbott, 1994, Te Punga, 1952). The formation appears to retain its heterolithic characteristics across the basin from Castlecliff to Rangitikei Valley (see **Figure 3.1**).

Plate 2.2.6 Lower Okehu Siltstone/Okehu Shell Grit contact at S22/129322 on upper Makuhou Road. Up to 3-4 m of the Lower Okehu Siltstone is visible at this outcrop where it consists of massive, blue-grey siltstone (Facies MZ-2) with 1.5 m of muddy siltstone at the top of the unit (see dashed line above spade handle). The contact between the blue-grey siltstone and the muddy siltstone is undulating up to 0.5 m. The sharp, bored contact with dm-scale relief marks the sequence boundary between Depositional Sequence 2 and 3. Approximately 1 m of faintly, large-scale planar cross-bedded medium sand (Facies WS-1), directly overlies this contact. This sandy unit is overlain by deposits described in Plate 2.2.7. (spade is approximately 1 m in length).

Plate 2.2.7 Uppermost Okehu Shell Grit at S22/129322 on upper Makuhou Road. Up to 4 m of parallel-laminated and planar cross-bedded fine sand with mud flasers and wavy bedding (Facies WS-2) overlies the units described in Plate 2.2.6 (spade is approximately 1 m in length).

Plate 2.2.6

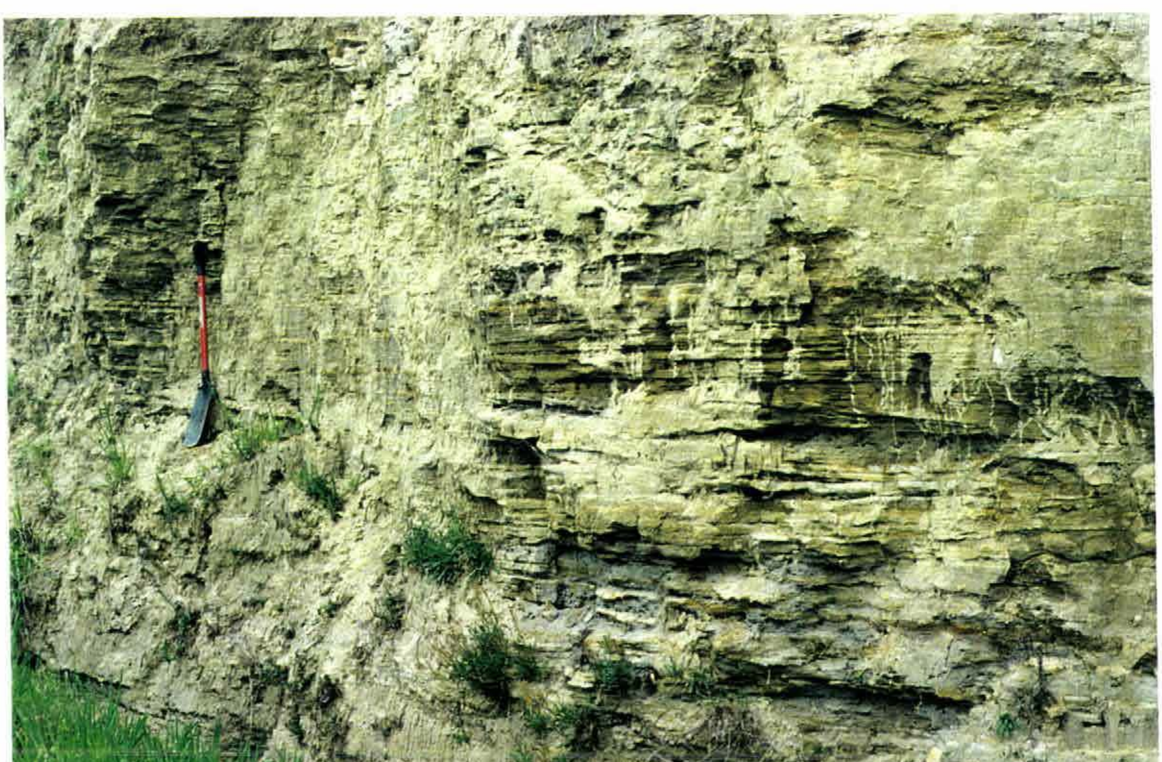


Plate 2.2.7

Upper Okehu Siltstone

Type Section : Castlecliff section between the mouth of Ototoka Stream and south-east to the mouth of Kai-iwi stream.

Name : name given by Fleming (1953) for the "Upper Okehu Silts" (Fleming, 1947a) at the coastal section.

Thickness : up to 20 m exposed along Turakina Valley Road. Abbott (1994) reported a thickness of 40 m in Turakina Valley at a site not visited by the writer.

Reference Section : S22/134320 Upper Makuhou Road.

Descriptive Sections : S22/072348 Turakina Valley Road, 400m north of the Makuhou Road turnoff.
S22/095307 Outcrop along stream bed, 2 km SE of the homestead, up small valley from the upper end of Morgans Road.

Descriptions

The Upper Okehu Siltstone at the reference section consists of 14 m of flaser and lenticular-bedded siltstone (Facies HE-2). The sand component at times displays small-scale ripple cross-lamination **[Plate 2.2.8]**. The formation becomes increasingly silty up - section (Facies HE-3) and appears unfossiliferous at this location. The unit culminates with at least 3 m of massive siltstone (Facies MZ-2). This section is summarised in **Figure 2.2.3**.

At DS (S22/072348) on Turakina Valley Road between Makuhou and Taurimu Roads, the Upper Okehu Siltstone consists of 6 - 8 m of massive, blue-grey siltstone (Facies MZ-2), with a thin, 0.2 m, band of shelly material approximately 1 m below the contact with the Deepdem Conglomerate (Potaka Pumice member of the Kaimatira Pumice Sand). The upper and lower contacts were not exposed at this site.

The Upper Okehu Siltstone at DS (S22/095307) 2 km up valley on the farm at the end of Morgans Road consists of up to 10 m of massive, blue-grey siltstone (Facies MZ-2), which progresses to a streaky-laminated, sparsely fossiliferous siltstone (Facies BZ-2) up valley. The upper contact is a sharp, wave - planed surface, overlain by the Potaka Pumice member (Deepdem Conglomerate) of the Kaimatira Pumice Sand.

The overall distribution of Depositional Sequence 3 is shown on the map and cross - section at the end of this thesis.

Palaeontology

A sample taken from the descriptive section at S22/072348 was dominated by *Mactra?* species.

Interpretation

The Upper Okehu Siltstone comprises the uppermost TST and the HST for Depositional Sequence 3 in the Wanganui Basin Plio - Pleistocene sequence.

The dominantly small - scale heterolithic and siltstone facies of the Upper Okehu Siltstone indicate deposition on the innermost to inner - middle shelf (section 2.1.4b and 2.1.4d). Like Depositional Sequence 2, the TST is made up largely of small - scale heterolithic facies with a similar interpretation for their occurrence. In hindsight, it may have been best to include these facies within the Okehu Shell Grit Formation and rename the formation for the Turakina Valley section.

The presence of the thin shellbed at the reference section, may suggest reworking of material farther up the shelf. The bivalve, *Mactra,* is generally associated with deposition in shallow water (estuarine) and therefore supports the interpretation that the shellbed deposits were transported into a deeper depositional environment.

Age and Correlation

The Upper Okehu Siltstone is assigned to Oxygen Isotope Stage 27 and attributed an age of 925 Ka by Abbott and Carter (1994), based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). As discussed in the previous section, the recent fission - track age of 1 Ma for the Potaka Pumice (Pillans *et al*, 1994), suggests an older age for the Upper Okehu Siltstone. Based on this new information, Pillans (1994) placed the Upper Okehu Siltstone within Oxygen Isotope Stage 29 (c. 1.2 Ma) (see **Figure 1.2**).

At the Castlecliff section, the formation consists of 5 - 6 m of barren, massive and finely laminated, blue-grey siltstone and includes a basal conglomerate member, 1 m thick which overlies the Okehu Shell Grit (Fleming, 1953). Abbott and Carter (1994) describe the formation as 5 m of cm - interbedded, streaky laminated, bioturbated siltstone, with a basal shellbed containing *Tiostrea* and *Dosina* which appears to be absent in Turakina Valley.

Facies of the siltstone member do not appear to change across the basin but the formation thickens dramatically towards Turakina Valley where it is up to 40 m thick (Abbott, 1994), although only 20 m was exposed at sites visited by the writer. Also note that much of the 20 m exposed is made up of small - scale heterolithic facies which represent the TST and should have been included as part of the Okehu Shell Grit Formation. In Rangitikei Valley, the formation is correlated with the siltstone unit directly below the Potaka Formation (Te Punga, 1952; Abbott, 1994; Pillans, 1994). The thickness of the formation in Rangitikei Valley decreases to 17 m (see **Figure 3.1**).

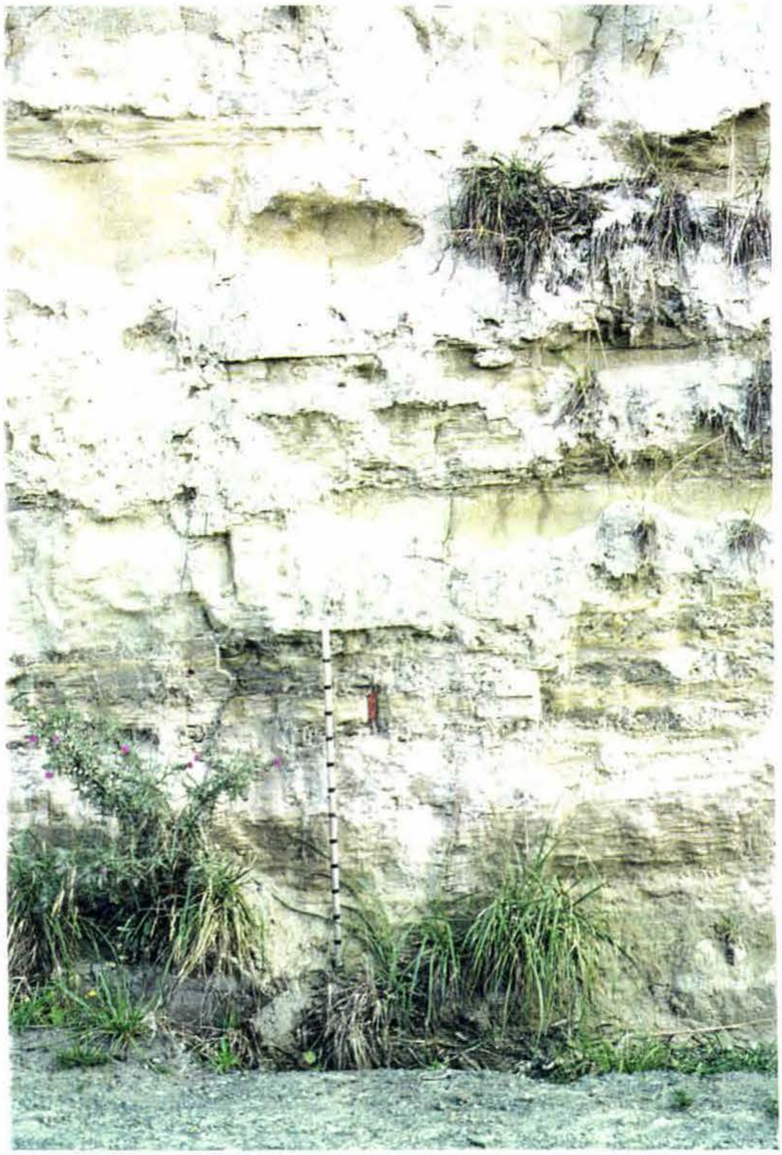
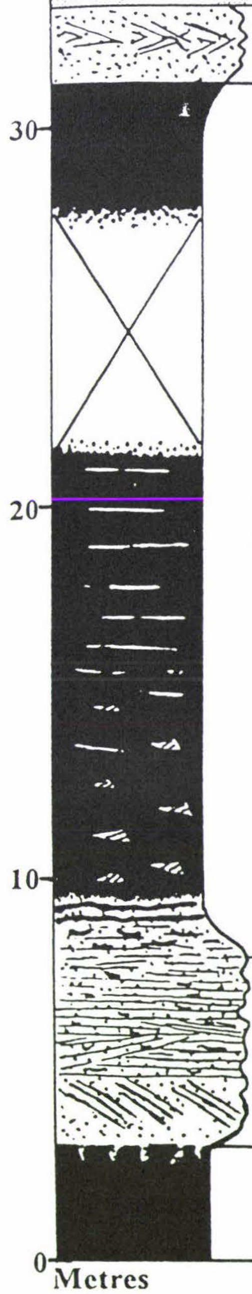


Plate 2.2.8 Lower part of the Upper Okehu Siltstone at S22/134320 on Upper Makuhou Road. The basal 1.5 m of the outcrop (see staff) consists of small-scale ripple cross-bedded fine sand with frequent mud flasers and wavy-bedding (Facies HE-2). Up to 2 m of dm-scale massive bedded and streaky-laminated siltstone (Facies HE-3) overlies this sandy unit. The sequence appears to be fining - up.



Stratigraphic Column	Descriptions	Facies Type	Interpretation	Seq. Strat.	Formation	
	Herringbone cross-bedded, pumiceous sand	HE-4	Tide/storm dom.'d innermost shelf	TST	Kaimatira Pumice Sand	DS 4
	Sequence Boundary Massive siltstone	MZ-2	Inner-middle shelf	HST	Upper Okehu Siltstone	DS 3
	Streaky-laminated siltstone	BZ-2 ↑ HE-3	Innermost shelf	TST		
	Lenticular and wavy-bedded fine sand	HE-2	Tide/storm dominated innermost shelf			
	Planar cross-bedded and parallel laminated f. sand	WS-2	Innermost shelf	TST	Okehu Shell Grit	
	Planar cross-bedded medium sand	WS-1	Wave-dominated shoreface			
	Sequence Boundary Massive siltstone	MZ-2	Inner-middle shelf	HST	Lower Okehu Siltstone	DS 2

Figure 2.2.3 Stratigraphic summary diagram for Depositional Sequence 3 in Turakina Valley at S22 129322 - 134320 along upper Makuhou Road. (See map and cross-section at the back of this thesis).

2.2.5 Depositional Sequence 4

Kaimatira Pumice Sand

Type Section : Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream.

Name : derived from the name 'Kaimatera beds' given to this formation by Hutton (1886). The basal, pumiceous member, the Deepdem Conglomerate, was named by Abbott (1994) from Deepdem farm off Turakina Valley Road, Turakina Valley.

Thickness : c. 33 m in Turakina Valley

Reference Section : S22/090310 - 094314 Newly cut farm track, 1.5 km up valley from homestead at end of Morgans Road.

Descriptive Sections :

S22/092312	Farm track east of S22/090310
S22/084312	Farm track running up valley from the farm house at the end of Morgans Road.
S22/069344	Turakina Valley Road and Makuhou Road intersection.
S22/137318	Makuhou Road and Smiths Road intersection.
S22/150357-156354	Upper Taurimu Road near Galpins Road.
S22/147366	Taurimu Road.

Descriptions

At the reference section, up to 5 m of coarse, strongly trough cross - bedded, poorly sorted, pumiceous sand with rare shelly lenses (Facies He-4), unconformably overlies the Upper Okehu Siltstone. The pumice is not very vesicular, difficult to break by hand and was identified as the Potaka Pumice **(sample T16, Appendix A)**. The lower contact is sharp and erosive with dm-scale relief and discontinuous, massive, mud drapes up to 1 m thick are present at some locations e.g. DS (S22/092312) on a farm track just to the north of the reference section. Convolute deformation structures are also apparent **[Plate 2.2.9]**. Approximately 28 m of unfossiliferous mainly interbedded fine sand and streaky-laminated siltstone (Facies HE-2 and HE-3) overlies the current bedded pumiceous member **[Plate 2.2.10]**. Where sand members are quite thick (2 - 4 m), small-scale planar cross beds occur and small (coarse sand - small pebble size) pumice fragments are present. Rare shelly lenses may also occur in these sandy members. The Kaukatea Ash was identified within the HE-3 facies of the Kaimatira Pumice Sand at S22/084312 on a farm track which begins at the farm house at the upper end of Morgans Road. The Kaukatea Ash here is made up of 0.3 - 0.7 m of fine white ash. It was not possible to reach the top of the outcrop and therefore a sample of the ash was not taken. The Kaukatea Ash was therefore identified on the basis of stratigraphic position rather then chemical signature. The upper contact of the Kaimatira Pumice Sand at the reference section is gradational over several cm. The upper contact at DS (S22/069344) is very sharp with little relief **[see Plate 2.2.13]**. These sections are summarised in **Figure 2.2.5**. The basal, pumiceous member (the Deepdem Conglomerate) is again seen at DS (S22/137318) at the intersection of Makuhou Road and Smiths Road, where it displays large-scale herringbone and trough cross-bedding.

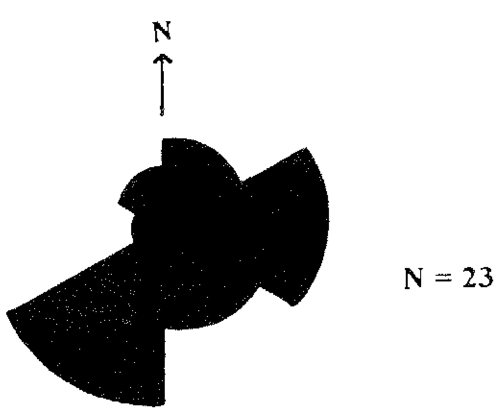
The Kaimatira Pumice Sand is also exposed on Taurimu Road at S22/150357-156354 where large-scale cross-bedding (only foresets evident) and mud drapes are a common feature. The lower contact was not exposed and the upper contact into fine - medium, well-sorted sand **(sample S41, Appendix B)** is gradational over at least 2 m into the undifferentiated Lower Kai-iwi and Westmere Siltstones. The pumice at this site was identified as the Potaka Pumice **(samples T 31, Appendix A)** and the unit is approximately 7 m thick. The Makuhou Shell Conglomerate is absent at this location and the Kaimatira Pumice sand grades into the undifferentiated Lower Kai-iwi and Westmere Siltstone. The occurrence of the Galpin Fault, with a vertical displacement of up to 500 m (Hellstrom, 1993) accounts for the Kaimatira Pumice Sand being evident so far north-east of the sites off Morgans Road i.e. the formation on Taurimu Road occurs on the down thrown side of the fault.

Another site on Taurimu Road (S22/147366) again reveals the basal Kaimatira Pumice Sand member (Deepdem Conglomerate). Here, c. 1m of crumbly, wavy and lenticular-bedded, muddy silt is overlain by a 20-30 mm pumiceous grit **(sample T27, Appendix A)**. This grit is covered by a thick, 0.8 m white ash **(sample T28, Appendix A)** with faint laminations (not visible in photo) which is sharply overlain by a poorly - sorted pumiceous conglomerate **(sample S46, Appendix B)** (Facies HE-4) **(sample T29, Appendix A), [Plates 2.2.11 and 2.2.12]**. Up to 2 m of this pumiceous conglomerate is exposed and the outcrop is then obscured. Samples T 27 and T 28 are chemically similar to the Kupe Tephra but when plotted on a ternary diagram they lie within an acceptable position for the Potaka Pumice (see section 3.6). Sample T 29 is very similar to the Potaka Pumice. The overall distribution of Depositional Sequence 4 is shown on the map and cross - section at the end of this thesis.

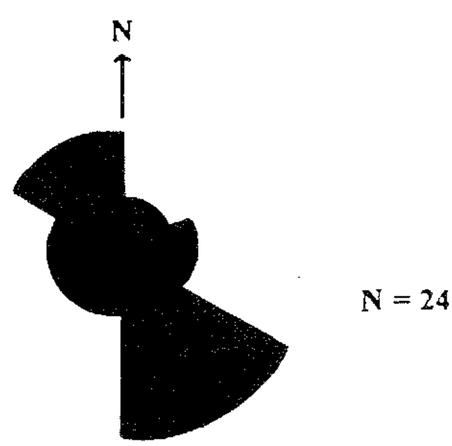
Palaeontology

Shelly lenses found within the current bedded basal member and subsequent overlying sand members (Facies HE-2), are dominated by *Paphies* species, indicating a shallow - water, possibly estuarine, environment of deposition.

Paleocurrent Data



a)



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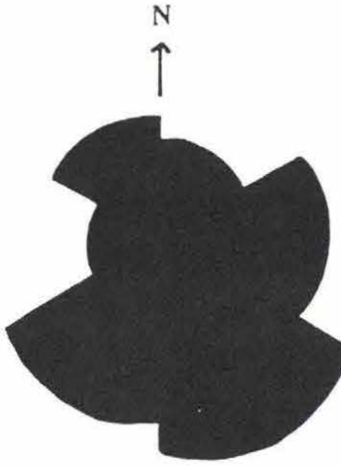
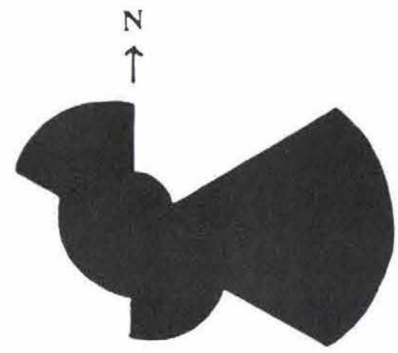


c)



d)

Figure 2.2.4 Rose diagrams of paleocurrent data taken from the basal member of the Kaimatira Pumice Sand (Deepdem Conglomerate) from a) S22/090310 on the farm at the end of Morgans Road; b) several sites near to S22/090310; c) data from a) and b) combined; d) S22/137318 on the corner of Makuhou Road and Smiths Road. Rose diagrams show that the current flow direction was variable overall and bimodal at each individual site which suggests a tidal influence (**Appendix C**).

<u>**Interpretation**</u>

The Kaimatira Pumice Sand comprises the TST for Depositional Sequence 4 in the Wanganui Basin, Plio-Pleistocene sequence. The HST for Depositional Sequence 4 is not represented in Turakina Valley or elsewhere across the onland part of the basin. The eruptive event that produced the sediment deposited at this time, largely increased the sediment supply into the basin. The increased sedimentation was balanced by subsidence only allowing deposition of more shallow - water, heterolithic TST facies throughout most of the sea-level cycle.

The Kaimatira Pumice Sand was deposited after an erosional interval upon the Upper Okehu Siltstone. This lower contact marks the lower sequence boundary for Depositional Sequence 4. A large volume of pumiceous material was washed down catchments originating near the sediment source in the Taupo Volcanic Zone. This material built out to form an estuarine delta at the coastline at a time of sea-level rise.

The presence of *in situ Paphies sp.* supports this interpretation. The occurrence of trough cross-bedding within the basal member of this formation and the bimodal directions of deposition also supports a deltaic environment of deposition. Convolute deformation structures indicate rapid deposition and are most likely syn-depositional (Seward, 1974). The majority of the formation is made up of Facies HE-2 and HE-3. The unfossiliferous nature of these members may indicate that deposition was too rapid and/or conditions too turbulent, for fauna to thrive. Mud drapes observed within the basal member most likely indicate slack water periods where fine-grained material settled out of suspension (Reineck and Singh, 1975).

Faint laminations observed within the fine, white ash at S22/147366 on Taurimu Road, and the fact that the unit is enclosed in shallow marine facies, probably indicates that the ash was water - transported rather than wind - transported.

Age and Correlation

A fission track age of 1 Ma has been assigned to the Potaka Pumice (Pillans *et al*, 1994). Abbott and Carter (1994) placed the Kaimatira Pumice Sand within Oxygen Isotope Stage 25 based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Pillans (1994) placed the Matuyama/Jaramillo boundary at the base of the Potaka Pumice. He included the Potaka Pumice member of the Kaimatira Pumice Sand within Oxygen Isotope Stage 27 and the overlying HE-2 and He-3 units within Oxygen Isotope Stage 25 (see **Figure 2.1**).

Across the basin, the formation thickens from 15 m at the Castlecliff section (Fleming, 1953; Abbott and Carter, 1994; Abbott, 1994), to over 30 m in Turakina Valley which may be attributed to closeness to the source of the sediment. The nature of the formation, however, does not appear to change greatly across the basin. The Kaimatira Pumice Sand is represented by the Potaka Pumice Formation in Rangitikei Valley (Te Punga, 1952; Abbott, 1994) and according to Abbott (1994) is c. 80 m thick (see **Figure 3.1**), and this reflects the existence of a major conduit of the Potaka Pumice down the Rangitikei River.

Plate 2.2.9 Basal member (Deepdem Conglomerate) of the Kaimatira Pumice Sand at a site east of S22/090310 c. 1.5 km up stream from the farmhouse at the end of Morgans Road. At least 2 m of large-scale trough cross-bedded pumice sand (Facies HE-4) are seen in this plate. Well preserved mega-ripple structures are visible in the centre of the plate. Convolute deformation structures are evident at the top of the unit (spade at left edge of the photo is approximately 1 m in length). The pumice in this unit was identified as the Potaka Pumice.

Plate 2.2.10 Kaimatira Pumice Sand at a site near to S22/090310 c. 1.5 km up stream from the farmhouse at the end of Morgans Road. Interbedded silt and sand with flaser and lenticular bedding and streaky lamellae evident in individual units (Facies HE-2 and HE-3). These facies make up the majority of the Kaimatira Pumice Sand (Alan Palmer for scale).

Plate 2.2.9

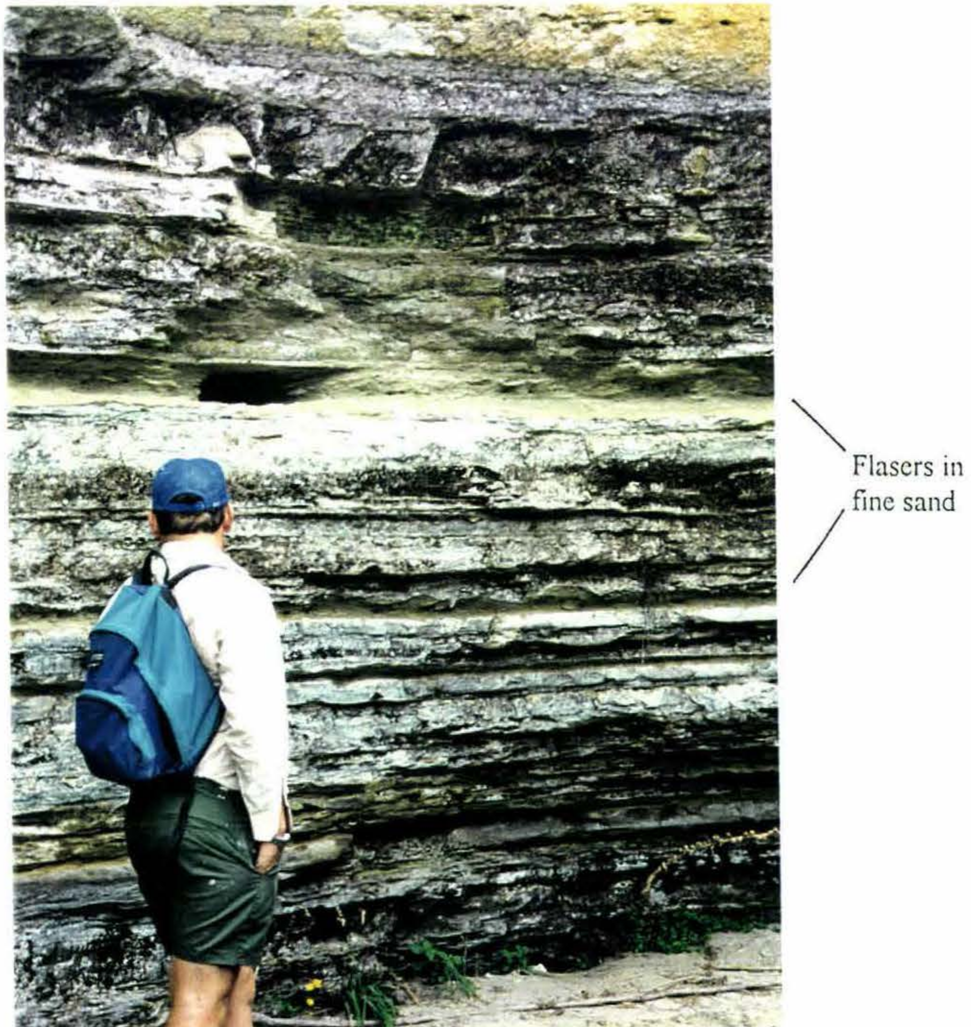


Plate 2.2.10

Plate 2.2.11 and 2.2.12 Basal member of the Kaimatira Pumice Sand at S22/147366, along Taurimu Road. A 20 - 30 mm pumiceous grit (sample T27) overlies up to 2 m of lenticular and wavy-bedded muddy silt. The pumiceous grit is overlain by c. 0.8 m of fine, white ash with very faint lamellae (sample T28). The top of this ash is undulating to dm-scale and is overlain by a unit of poorly-sorted pumiceous sand (sample T29). At least 1.5 m of this unit is exposed at this site (staff in Plate 2.2.11 is 1.5 m long and knife in Plate 2.2.12 is 40 cm long).

Plate 2.2.11

Plate 2.2.12

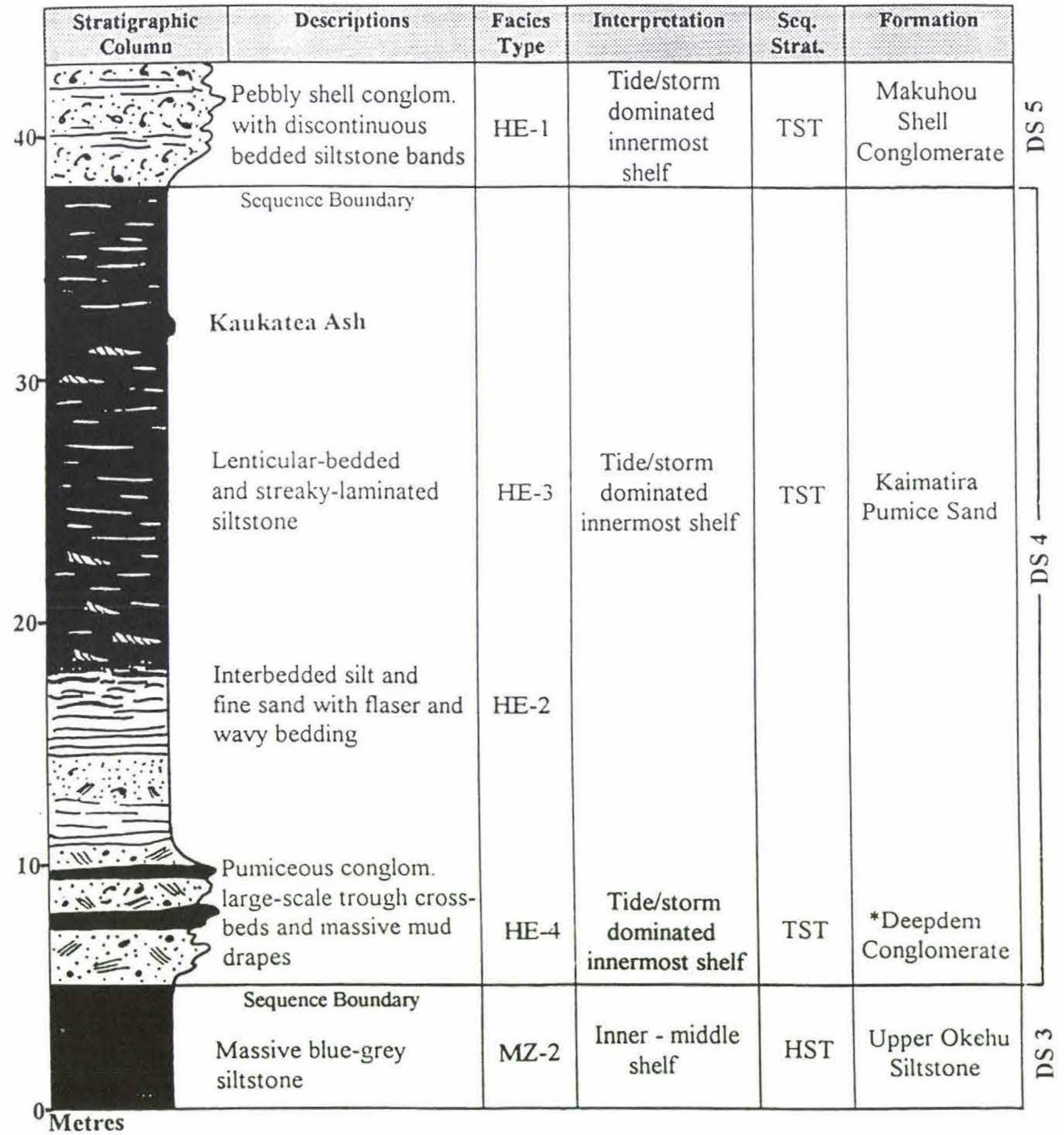


Figure 2.2.5 Stratigraphic summary diagram for Depositional Sequence 4 in Turakina Valley from site S22/090310 - 094314 on a farm track c. 1.5 km up valley from the upper end of Morgans Road (See map and cross-section at the back of this thesis).

* name given by Abbott (1994) to the basal pumiceous conglomerate of the Kaimatira Pumice Sand.

2.2.6 Depositional Sequence 5

Makuhou Shell Conglomerate

Type Section : Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream.

Name : proposed by Abbott (1994) for the shell conglomerate previously considered as the upper part of the Kaimatira Pumice Sand (Fleming, 1953). An outcrop of the formation on Turakina Valley Road just south of the Makuhou Road turn off is the source of Abbott's name 'Makuhou Shell Conglomerate'.

Thickness : up to 7 m in Turakina Valley.

Reference Section : S22/069344 Turakina Valley Road and Makuhou Road intersection and 400 m south of this point.

Descriptive Sections : S22/092312 Newly cut farm track, 1.5 km up valley from the homestead at the end of Morgans Road.
S22/095313 Fairly recent track 400 - 500 m up valley from S22/092322.

Descriptions

A coarse, pebbly, pumiceous, shelly, very large-scale cross-bedded sand (Facies HE-1, Type A1 Shellbed) represents the Makuhou Shell Conglomerate at the reference section. Only the foresets of the cross-beds are visible. The lower contact with a massive, muddy silt member of the Kaimatira Pumice Sand, is sharp with little relief **[Plate 2.2.13]**. The upper contact is gradational over 1-2 m into a laminated siltstone (undifferentiated Lower Kai-iwi and Westmere Siltstones). This section is summarised in **Figure 2.2.6**.

At DS (S22/092312) on a steep farm track 1.5 km from the end of Morgans Road, the formation appears as interfingering coarse, pebbly, shelly, pumiceous sand bodies (Facies HE-1) **[Plate 2.2.14]**. Here the shellbed is up to 7 m thick. The lower contact is gradational over a few centimetres. However, disrupted bedded siltstone similar to the unit beneath, continues between the shelly sand bodies. At the upper contact, the formation grades into a laminated, fine sand which probably represents the lower part of the undifferentiated Lower Kai-iwi and Westmere Siltstones. Chemical analysis of the pumice found within this formation indicates that it is dominantly Potaka Pumice **(sample T40, Appendix A)**. The Kaukatea Ash has also previously been found within this formation (Abbott, 1994).

A sharp wave-planed surface below the shell conglomerate is evident at DS (S22/095313) on a farm track c. 2 km up valley from the end of Morgans Road. The formation displays similar lithology and faunal assemblages to DS (S22/092312) but has distinct cross-bedding structures which are only visible as foresets **[Plate 2.2.15]**.

The overall distribution of Depositional Sequence 5 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection Site : S22/092312 (S22/ f 155)

The faunal assemblage is dominated by an unnamed *Paphies* species which has also been found in abundance in the formation at Kaimatira and at Kaimatira Bluff (Beu pers. comm., 1994) **[Table 2.2.1]**. Fauna were most likely transported into the site of deposition (section 2.1.4b).

Interpretation

The Makuhou Shell Conglomerate forms the transgressive systems tract of Depositional Sequence 5 in the Turakina Valley, Plio-Pleistocene sequence.

Facies indicate deposition within the tide/storm dominated innermost shelf (section 2.1.4b). The graded lower contact at DS (S22/092312) on a steep farm track at the end of Morgans Road, indicates that no erosion took place at this site during the rise in sea-level. Where a sharp contact occurs at the lower sequence boundary, the underlying siltstone appears more massive as opposed to laminated, and the wave-cut platform is better expressed. The upper contact is conformable with the overlying sediments of the undifferentiated Lower Kai-iwi and Westmere Siltstones.

Age and Correlation

Abbott and Carter (1994) assigned the Makuhou Shell Conglomerate to Oxygen Isotope Stage 23 based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Seward (1974) reported a fission-track age of c. 570 Ka for the Kaukatea Ash which was dated from the equivalent formation in Rangitikei Valley. However, based on a recent fission-track age of 1 Ma for the Potaka Pumice (Pillans *et al*, 1994), it is reasonable to estimate an older age of c. 900 Ka for the Kaukatea Ash (Abbott and Carter, 1994). Pillans (1994) indicates an age of c. 850 Ka for the Kaukatea Ash and places it within Oxygen Isotope Stage 21 (see **Figure 1.2**).

The thickness of the formation increases from 1.7 m at the Castlecliff section (Fleming, 1953) to 7 m in Turakina Valley but the nature of the formation is similar. The Makuhou Shell Conglomerate is correlated with the Waitapu Shell Conglomerate in the Rangitikei Valley (Te Punga, 1952; Seward, 1974; Abbott, 1994; Pillans, 1994) (see **Figure 3.1**).

Table 2.2.1 Palaeontology of the Makuhou Shell Conglomerate in Turakina Valley.

FAUNA	f 155
Bivalvia	
Anomia trigonopsis	p
Glycymeris modesta	p
Paphies n. sp.	c
Pleuromeris marshalli	p
Pleuromeris zealandica	s
Purpurocardia sp.	p
Purpurocardia purpurata	f
Talochlamys gemmulata	p
Tawera sp.	p
Tiostrea chilensis	p
Tucetona laticostata	p
Gastropoda	
Amalda (Baryspira) mucronata	p
Amalda (Gracilispira) novaezelandiae	p
Antimelatoma buchanani	p
Antizafra ? pisanoides	p
Aoteadrilla wanganuiensis	p
Bathytoma (Micantapex) murdochi	p
Buccinulum sp.	p
Callistroma mukumaruensis	p
Cirsotrema zelebori	p
Crepidula ' radiata '	s
Maoricolpus roseus	s
Paracomitas protransenna	p
Pelicaria sp.	p
Penion adustus	p
Pervicacia tristis	p
Seila sp.	p
Stiracolpus sp.	s
Tanea sp.	p
Xymene ambiguus	p
Xymene expansus	p
Xymene pusillus	s
Zafra imedita	p
Zeacolpus vittatus	p
Zegalerus tenuis	p
Zemitrella ? choave	p
Zethalia zelandica	p

Table 2.2.1 continued

FAUNA - GASTROPODA CONT'D	f 155
Scaphopoda	
Antalis nana	s
Brachiopoda	
Waltonia inconspicua	p
Arthropoda/Cirripedia (barnacla plate)	p
Bryozoa (branching type)	s

[Fauna identified by Alan Beu]

p = present

f = few

s = several

c = common

a = abundant

Plate 2.2.13 Makuhou Shell Conglomerate at S22/069344 on Turakina Valley Road, c. 400 m up hill, south of the Makuhou Road turnoff. Very large-scale foresets within a pebbly shell conglomerate (Facies HE-1, Type A1 Shellbed) make up the Makuhou Shell Conglomerate at this location. A very sharp contact with a muddy silt unit of the Kaimatira Pumice Sand can be seen to the right of the plate. This contact marks the sequence boundary between Depositional Sequence 4 and 5.

Plate 2.2.14 Makuhou Shell Conglomerate at S22/092312 on a farm track, c. 1.5 km up valley from the farmhouse at the end of Morgans Road. Shelly, pebbly, pumiceous sand bodies are interfingered with laminated silt deposits (Facies HE-1, Type A1 Shellbed). The contact with the underlying units of the Kaimatira Pumice Sand is gradational over several cm.

Plate 2.2.15 Makuhou Shell Conglomerate at S22/095313, c. 400 m up valley from Plate 2.2.14. A pebbly shell conglomerate with prominent foresets makes up the formation at this site (Facies HE-1, Type A1 Shellbed). Individual foresets seem to fine upwards.

1 m

Plate 2.2.14

1 m

Plate 2.2.15

Lower Kai-iwi and Westmere Siltstone (undifferentiated)

Type Section : Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream.

Name : based on the "Kai-iwi Blue Clays" and "Cl 8 Lower Westmere Silts" of Fleming (1947a).

Thickness : 35 - 50 m in Turakina Valley

Reference Section :	S22/077319	Farm track near western boundary fence, and above a small stream on the farm at the end of Morgans Road.
Descriptive Sections :	S22/092312	Newly cut, steep track, 1.5 km up valley from the homestead at end of Morgans Road
	S22/095316	Farm track 500 m north-east of S22/092312
	S22/072306	Steep track 2.4 km up valley from Turakina Valley Road on farm located between Waimutu and Morgans Roads.

Descriptions

Approximately 10 m of streaky laminated, blue-grey siltstone (Facies BZ-2), followed by 40 m of massive, barren, blue-grey siltstone (Facies MZ-2), represents the undifferentiated Lower Kai-iwi and Westmere Siltstone at the reference section. The lower contact is not exposed. The upper contact is an undulating wave-cut platform, locally bored by *Anchomasa (Barnea) similis* (Type C Shellbed). This section is summarised in **Figure 2.2.6**.

At the descriptive sections, the formation is made up of 7 - 10 m of streaky-laminated siltstone followed by c. 35 - 40 m of massive, barren blue-grey siltstone, terminating with 2 m of muddy, brown siltstone with numerous shell imprints. The contact between the blue-grey siltstone and the muddy siltstone is undulating to dm-scale **[Plate 2.2.16]**.

The formation at DS (S22/092312) on a steep farm track, 1.5 km east of the end of Morgans Road, has 7 m of fine, very well - sorted **(sample S30, Appendix B)**, parallel laminated sand (Facies WS-2) below the streaky-laminated siltstone member which may make up the upper part of the Makuhou Shell Conglomerate or the basal member of the siltstone formation at this site.

The overall distribution of Depositional Sequence 5 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Generally unfossiliferous. The shell impressions seen within the uppermost muddy siltstone unit include species such as *Zethalia* and (?)*Leucotina* which is consistent with deposition on the inner shelf.

Interpretation

The undifferentiated Lower Kai-iwi and Westmere Siltstones represent the HST of Depositional Sequence 5 in the Wanganui Basin sequence.

Facies indicate deposition on the inner - middle shelf (section 2.1.4d). The sharp upper contact marks the upper sequence boundary (wave-cut platform) for Depositional Sequence 5. The well - sorted sand at the base of the formation at DS (S22/092312) indicates deposition in a wave - dominated shoreface environment (section 2.1.4a).

The muddy unit at the top of the formation may indicate a period of sediment starvation.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990), Abbott and Carter assigned the undifferentiated Lower Kai-iwi and Westmere Siltstone to the upper part of Oxygen Isotope Stage 21 and 23 and attributed an age of c. 800 - 830 Ka to the formation. Pillans (1994) placed these formations within Oxygen Isotope Stage 21 (see **Figure 1.2**).

At the Castlecliff section, the Lower Kai - iwi Siltstone and the Lower Westmere Siltstone are separated by the Omapu Shellbed, *Ophiomorpha* Sand, and the Lower Westmere Shellbed (Abbott and Carter, 1994), all of which are absent in Turakina Valley. The MCS for Depositional Sequence 5 is therefore not represented in Turakina Valley indicating that sedimentation was continuous and complete sediment starvation never occurred

The thickness of the formation increases markedly from the Castlecliff section to Turakina Valley. Fleming (1953) reported a thickness of 13 m at the Castlecliff section. Pillans *et al* (1994) indicate a thickness of 80 m for the formation in Turakina Valley, however height data gathered here **(Appendix D)**, indicates a thickness of 35-50 m in Turakina Valley. Abbott (1994) reported a thickness of 45 m in Rangitikei Valley.

The nature of the formation, aside from thickness, does not appear to change greatly across the basin. The Rangitikei correlative is the siltstone unit between Waitapu Shell Conglomerate and the Kaikokopu Shellbed (Abbott, 1994; Pillans, 1994) (see **Figure 3.1**).

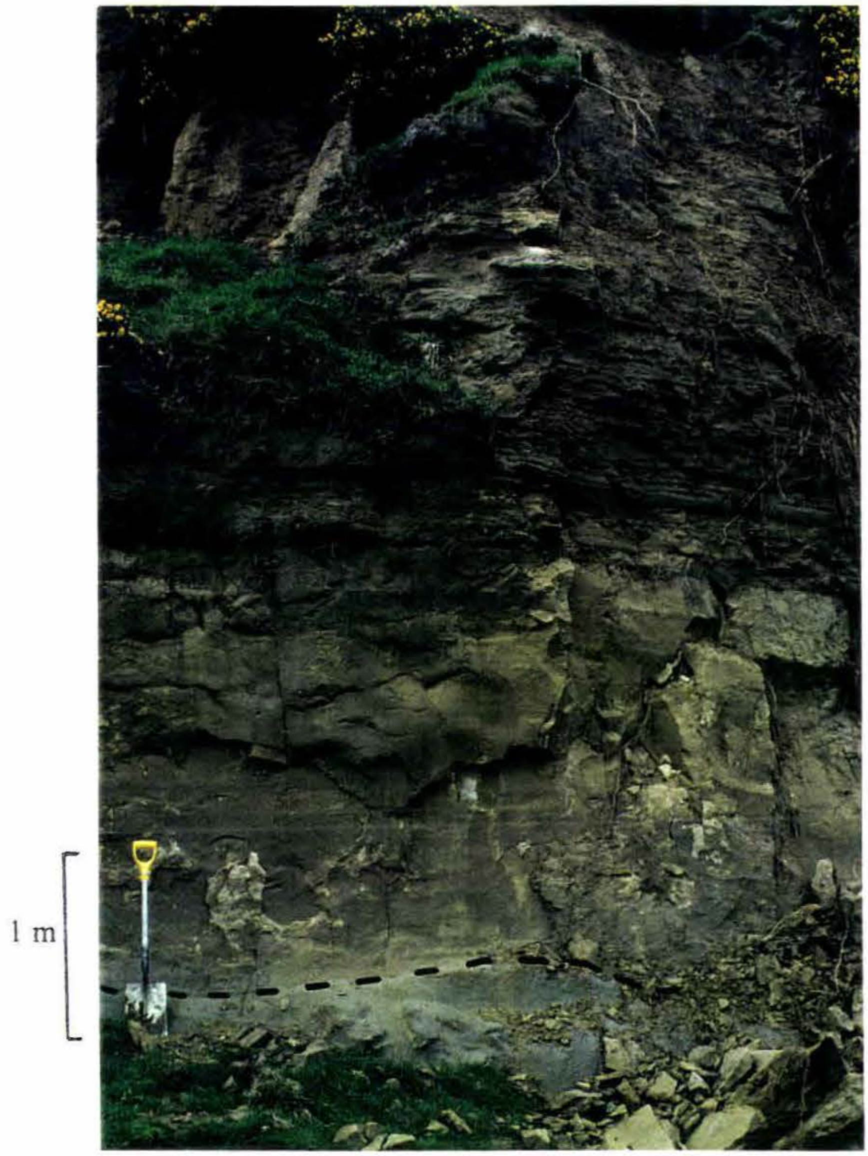


Plate 2.2.16 Lower Kai-iwi and Westmere Siltstone at S22/095316 on a farm track, 2 km NE of the farmhouse at the end of Morgans Road. At the base of the outcrop, the massive blue-grey siltstone (Facies MZ-2) with an upper undulating surface is overlain by 2 m of more muddy siltstone with shell impressions (see dashed black line). The sharp contact above this unit marks the sequence boundary between Depositional Sequence 5 and 6. The Kaikokopu Shell Grit is absent at this site and the bedded siltstone unit above the sequence boundary is most likely another lower unit within the Ruakina Formation.

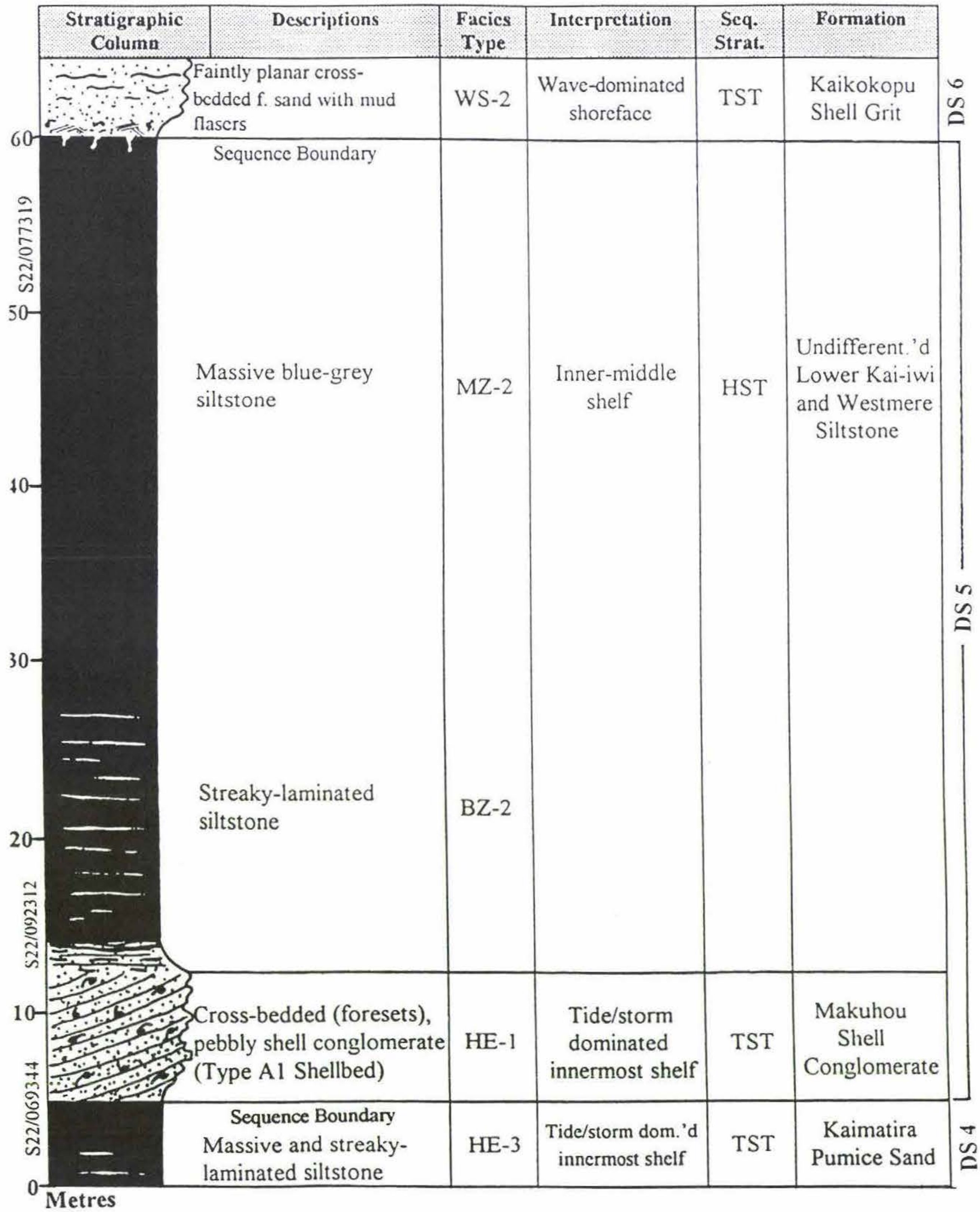


Figure 2.2.6 Stratigraphic summary diagram for Depositional Sequence 5 in Turakina Valley from site S22/069344 at the Turakina Valley Road/Makuhou Road intersection and from site S22/077319 and S22/092312, 1.5 km up valley from the upper end of Morgans Road (See map and cross-section at the back of this thesis).

2.2.7 Depositional Sequence 6

The formations comprising Depositional Sequence 6 in Turakina Valley are somewhat different to those at the Castlecliff section. At the Castlecliff section, Depositional Sequence 6 is largely made up of the Upper Westmere Siltstone, where the Kaikokopu Shell Grit represents the basal member (Fleming, 1953; Abbott and Carter, 1994; Abbott, 1994). The formations in Turakina Valley quite clearly represent the TST, MCS and HST of a typical Wanganui - type depositional sequence, and for the sake of consistency in terms of sequence stratigraphy, are named accordingly. All the units above the Kaikokopu Shell Grit member described in the following text, are equivalent to the Upper Westmere Siltstone at the Castlecliff section. In Turakina Valley, the Kaikokopu Shell Grit forms the basal member of a formation here named the Ruakina Formation.

Ruakina Formation (New)

Type Section : The type section for the Kaikokopu Shell Grit member of the Ruakina Formation is the Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream. The Ruakina Formation was described from S22/089323 - S22/092321 on a farm track between Morgans Road and Makuhou Road in Turakina Valley.

Name : the Kaikokopu Shell Grit member was named from a well exposed road cutting of this formation on Kaikokopu Road, west of Aramoho (Fleming, 1953). The name Ruakina Formation (RF) is proposed here for the Kaikokopu Shell Grit member (KSG) and overlying units representing the TST. The name Ruakina is taken from the farm by that name at the end of Morgans Road in Turakina Valley.

Thickness : the Kaikokopu Shell Grit member ranges between 3-7 m in Turakina valley and the Ruakina Formation as a whole, is up to 44 m **(Appendix D)**.

Descriptive Sections : S22/077319 Farm at the end of Morgans Road. Outcrop on farm track 1 km north of the homestead (KSG).

S22/072306	Farm track between Morgans Road and Waimutu Road (KSG).
S22/069318	Morgans Road; small outcrop on roadside (KSG).
S22/086331	Farm track between Morgans Road and Makuhou Road (KSG).
S22/093314	Steep, new track on farm at end of Morgans Road (KSG).
S22/091317	Bulldozed ridge line on farm at end of Morgans Road (KSG).
S22/056323	Cliff face above Turakina River and off Turakina Valley Road, 200 m south of the Morgans Road turnoff (RF).

Descriptions

A well exposed, complete outcrop of the Kaikokopu Shell Grit member occurs at the type section for the Ruakina Formation in Turakina Valley. The formation lies unconformably on the wave-planed surface of the Lower Kai-iwi and Westmere Siltstones. Here the unit is comprised of a coarse, pebbly, poorly-sorted, planar cross-bedded (foresets), sand with abundant, scattered shells and frequent mega-flaser structures which follow bedding planes (Facies HE-1, Type A1 Shellbed). Intermittent, mud drapes up to 0.5 m thick also occur (Facies HE-3) **[Plate 2.2.17 and 2.2.18]** and the thickness of the formation at this location is 3-4 m. The Kaikokopu Shell Grit grades into heterolithic and sandstone facies which are thought to comprise the majority of the Ruakina Formation. This section is summarised in **Figure 2.2.8**. The Kaikokopu Shell Grit member at DS (S22/086331) is very similar to this, except that the cross bedding is large-scale herringbone cross-bedding **[Plate 2.2.19]**. Clear burrowing at the lower contact is evident (Type C Shellbed) **[Plate 2.2.20]**.

At the type section for the Ruakina Formation, at least 37 m **(Appendix D)** of sediment overlies the Kaikokopu Shell Grit member. Most of the unit is not exposed. The unit lying conformably above the Kaikokopu Shell Grit member, of which up to 2 m is exposed, is wavy-bedded and made up of heterolithic facies (Facies HE-2). Farther up the track at S22/092321, approximately 3 m of the Ruakina Formation is exposed below a Type B shellbed, which is referred to in this thesis as the Morgans Shellbed. This upper unit is a coarse silt **(sample S43, Appendix B)** with scattered fauna (Facies ZS-2) mostly concentrated in a band c. 0.3-0.4 m thick, and 2.6 m below a relatively sharp contact with the Morgans Shellbed **[see Plate 2.2. 24]**.

The Kaikokopu Shell Grit member at DS (S22/077319) on a farm track c. 0.75 km north-west of the end of Morgans Road, is a fine, faintly cross-bedded, well-sorted sand (Facies WS-2), approximately 7 m thick. At the base, a 0.2-0.3 m thick, pumiceous **(T39, Appendix A)** sandy shell grit occurs. The chemical signature of this pumice as a whole indicates reworking of Potaka Pumice. This pumiceous grit was also observed at DS (S22/069318) on Morgans Road. The shell grit lies upon the wave-planed and bored surface of the undifferentiated Lower Kai-iwi and Westmere Siltstone. Although not seen at DS (S22/077319), flaser and wavy-bedding appear approximately halfway up the formation on Morgans Road **[Plate 2.2.21]**.

At DS (S22/072306) between Waimutu and Morgans Roads, the Kaikokopu Shell Grit is composed of a fine, planar cross-bedded, well-sorted sand **(sample S25, Appendix B)**, with rare coarse-grained discontinuous shell lags (Facies WS-2). Muddy laminations are common and increase in occurrence as the unit grades into the overlying unit of the Ruakina Formation. The Kaikokopu Shell Grit is approximately 3.5 m thick at this location **[Plate 2.2.22]**.

At DS S22/093314 and S22/091317, 1.5 and 1.2 km (respectively), up valley from the end of Morgans Road, the Kaikokopu Shell Grit is made up of c. 5m of large (1-1.5 m thick) discontinuous, coarse, pebbly, poorly-sorted, shelly sand bodies within a medium-coarse sand. Faint planar cross-bedding was observed at DS (S22/093314) at the top of a newly cut, steep farm track.

Only the uppermost part of the Ruakina Formation is exposed at DS (S22/056323) at a cliff face above Turakina River 200 m south of the Morgans Road turnoff. At least 2 m of interbedded silt and sand with occasional coarser, shelly lenses is overlain by a fossiliferous(?) greywacke conglomerate which is approximately 1.5 m thick. Up to 1 m of loose, fossiliferous sand (f 154a) overlies the conglomerate. This shelly sand is overlain by a Type B shellbed which is most likely the Morgans Shellbed. The overall distribution of Depositional Sequence 6 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection sites :	S22/072306	(S22/ f 152) (KSG)
	S22/093314	(S22/ f 156) (KSG)
	S22/091317	(S22/ f 157) (KSG)
	S22/077319	(S22/ f 158) (KSG)
	S22/089323	(S22/ f 159) (KSG)
	S22/086331	(S22/ f 160) (KSG)
	S22/092321	(S22/ f 150) (RF)
	S22/056323	(S22/ f 154a) (RF)

Fauna from samples S22/ f 158, 159 and 160 are generally abraded, diverse and often indicative of older strata, suggesting erosion of these older formations and transportation into a new environment. Fauna such as *Paphies n. sp.* and *Xymene expansus* **[Table 2.2.2]** indicate deposition in a very shallow water environment such as a sheltered sandy beach or a sheltered bay (Beu pers. comm., 1995) and must therefore have been transported into a deeper water, innermost shelf environment.

The faunal assemblage from sample S22/ f 150 from the shellbed in coarse silt at the top of the Ruakina Formation, is dominated by *Tiostrea* and a distinctive abraded form of *Pecten marwicki* **[Table 2.2.2]**. A similar shellbed was found in the Upper Westmere Siltstone at the Castlecliff section (1.3 m above the Kaikokopu Shell Grit) and was named the Upper Westmere Shellbed (Abbott and Carter, 1994). In Whangaehu Valley, the shellbed occurs 6-10 m above the contact with the Kaikokopu Shell Grit (Beu pers. comm., 1995).

Two *Pecten* specimens found within the shellbed at the type section for the Ruakina Formation resembled *Pecten novaezelandiae*, a subspecies similar to that found in the stratigraphically higher Waiomio Shellbed in Rangitikei Valley (Beu pers. comm., 1995). The FAD of *Pecten* in the Turakina Valley sequence occurs at the top of the Ruakina Formation, which is equivalent to the Upper Westmere Siltstone at Castlecliff. The facies and fauna of the shellbed indicate deposition in a slightly deeper - water environment than the Kaikokopu Shell Grit.

All shell material from sample S22/ f 154a is abraded and most likely long-shore transported. The assemblage resembles a beach accumulation (Beu pers. comm., 1995).

Paleocurrent Data

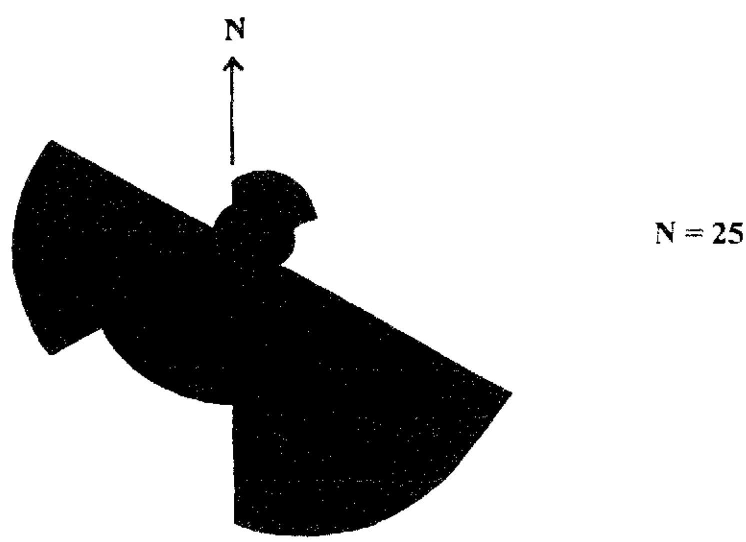


Figure 2.2.7 Rose diagram of paleocurrent data from S22/072306 (KSG), a farm track between Waimutu Road and Morgans Road (**Appendix C**). The bimodal nature of the paleocurrent data taken from a planar cross-bedded sandy unit, indicates that tides dominantly influenced sedimentation (Reineck and Singh, 1975). The current trends north - west and south - east.

Interpretation

The Ruakina Formation forms the TST for Depositional Sequence 6 in the Turakina Valley sequence.

Deposition of the Kaikokopu Shell Grit member followed an erosional interval where the undifferentiated Lower Kai-iwi and Westmere Siltstones were subjected to wave planation. Between tide levels, the bivalve *Anchomasa (Barnea) similis* bored into the planed surface (Type C Shellbed) **[Plate 2.2.20]**. A sandy shell-lag was deposited as the sea transgressed landward. Overall, the Kaikokopu Shell Grit member represents deposition on a tide and possibly storm dominated innermost shelf (section 2.1.4b), with fauna derived from erosion of older formations and other, contemporaneous environments. The bimodal nature of paleocurrent direction supports this interpretation. The lower contact represents the lower sequence boundary for Depositional Sequence 6.

The thick unit of heterolithic and silty sandstone facies above the Kaikokopu Shell Grit member may indicate either that the Marton Anticline was actively uplifting at the time or that a major sediment source was diverted to this part of this basin (see section 3.2). The shellbed near the top of the Ruakina Formation most likely represents a short diastem, making conditions more suitable for faunal activity. The upper, quite sharp contact with the Morgans Shellbed represents the Local Flooding Surface.

Sandy facies representing the upper Ruakina Formation at S22/056323 at a cliff face above Turakina River, 200 m south of the Morgans Road turnoff indicate shallow - water, probably shoreface conditions.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) Abbott and Carter (1994) assigned the Kaikokopu Shell Grit to the lower part of Oxygen Isotope Stage 19 which marks the position of the Bruhnes/Matayama boundary (c. 780 Ka, Abbott and Carter, 1994; Pillans, 1994) (see **Figure 1.2**). The overlying deposits in Turakina Valley which are equivalent to the lower part of the Upper Westmere Siltstone at Castlecliff, were also deposited during Oxygen Isotope Stage 19 (Abbott and Carter, 1994, Pillans, 1994). Across the basin, the thickness of the Kaikokopu Shell Grit changes quite markedly from c. 0.15 m at Castlecliff to 7 m in Rangitikei Valley. The nature of the Kaikokopu

Shell Grit differs across the basin only in regard to the matrix of the deposits and more pronounced sedimentary structures. The matrix of the Kaikokopu Shell Grit east of Wanganui is made up of a pumiceous sand. The Kaikokopu Shell Grit can be correlated to Rangitikei where it is called the Kaikokopu Shellbed (Abbott, 1994) (see **Figure 3.1**).

The shellbed at the top of the Ruakina Formation at the reference section is most likely equivalent to the Upper Westmere Shellbed at the Castlecliff section (Abbott and Carter, 1994).

Table 2.2.2 : Palaeontology of the Ruakina Formation in Turakina Valley

FAUNA	f 150	f 152	f 154a	f 156	f 157	f 158	f 159	f 160
Bivalvia								
Anchomasa (Barnea) similis				p		p	s	s
Aulacomya sp.	p							
Bassina yatei					p			
Carycorbula zelandica			f					
Chlamys gemmulata	p							
Cyclomactra sp.						p		
Cyclomactra tristis							p	
Dosinia zelandica	p							
Glycymeris modesta			c	f	p		p	f
Maorimactra n. sp.				p	s	c	s	c
Maorimactra ordinaria		p						
Myadora striata			p					
Myadora subrostrata	p							
Nemocardium pulchellum						p	f	p
Notocallista multistriata					p		p	
Nucula nitidula			p				f	
Paphies sp.	p							
Paphies n. sp.		a		c	s	c	a	c
Pecten benedictus marwicki	c							
Pleuromeris zealandica			s	f	f		s	s
Purpurocardia purpurorata			s	c	p	p		
Talochlamys gemmulata				f	f	p	p	p
Tawera spissa			s	s	s	p		p
Tiostrea chilensis lutaria	a		f	f	s	p	p	p
Gastropoda								
Aeneator marshalli			p					
Agatha georgiana							p	
Alcithoe arabica					p		p	
Alcithoe fusus			p	p				
Amalda sp.		p	p					
Amalda (Baryspira) australis			p		p	p	s	
Amalda (Baryspira) mucronata				p	f	p	p	
Amalda (Gracilispira) novaezealandia				f	c	s	s	c
Amphibola crenata								p
Antimelatoma buchanani								p
Aoteadrilla wanganuiensis							p	p
Austrofusus glans	p		p	p	f			f
Austromitra sp.						p		
Austromitra rubiginosa								p
Buccinulum sp.		p				p		
Buccinulum caudatum							p	
Buccinulum ? linea							p	p
Buccinulum vittatum				s				
Calliastroma ? cf. nukumaruensis				p				
Calliastroma selectum								p

Table 2.2.2 cont'd

FAUNA : GASTROPODA CONT'D	f 150	f 152	f 154b	f 156	f 157	f 158	f 159	f 160
Cirsotrema zelebori				p				
Crepidula ' radiata '				s	f			
Diloma subrostrata					p			
Globisinum drewi							p	
Leucotina ambigua				p	s	p	f	p
Liracraea ? odhneri								p
Maoricolpus roseus	f		f	s	c		s	p
Michrelenchus ? sanguineus			f					
Murexsul octogonus							p	
Neoguraleus sp.			p	p	p		f	p
Odostomia sp.			p					
Paratrophon sp.				p	p		p	
Peculator hedleyi			p					
Pelicaria vermis				p	p		p	
Penion sp.				p	p	p	p	
Pervicacia tristis		s			s		s	s
Phenatoma sp.			p					
Phenatoma novaezealandiae					p			
Phenatoma rosea				p				
Poirieria zelandica				p	p			
proxiuber australe					p	p	p	
Semicassis pyrum							p	
Stiracolpus aff. symmetricus				f			s	s
Stiracolpus sp.			p			p		
Stiracolpus ? murdochi					c			
Struthiolaria papulosa				p			p	p
Tanea zelandica				p			p	
Trochus tiaratus					p	p	p	p
Turbo smaragdus						p		
Xymene ambiguus				s	p		p	
Xymene bonnetti							p	
Xymene expansus		s	s	s	c	s	c	s
Xymene pusillus								f
Zafra sp.				p				
Zeacolpus vittatus				f	p	p	p	
Zegalerus tenuis			s				f	s
Zemitrella sp.							p	
Zethalia zelandica			p		c	p	f	f
Scaphopoda								
Antalis nana		p	p	p	f	p	c	s

[Fauna identified by Alan Beu]

p = present **c = common** **s = several**

f = few **a = abundant**

Plate 2.2.19 Lower Kai-iwi and Westmere Siltstone/Kaikokopu Shell Grit contact at S22/086331 on a farm track between Morgans Road and Makuhou Road (closer to Makuhou Road). The very sharp, bored contact marks the sequence boundary between Depositional Sequence 5 and 6. The Kaikokopu Shell Grit at this site is distinctly herringbone cross-bedded and is made up of a pebbly shell conglomerate (Facies HE-1, Type A1 Shellbed).

Plate 2.2.20 Close-up of the contact between the Lower Kai-iwi/Westmere Siltstone and the Kaikokopu Shell Grit at S22/086331. The intertidal bivalve *Anchomasa (Barnea) similis* is preserved within burrows (Type C Shellbed) (35 mm lens cap for scale).

Plate 2.2.17 Lower Kai-iwi and Westmere Siltstone/Kaikokopu Shell Grit contact at S22/089323 on a farm track between Morgans Road and Makuhou Road. The contact between the Lower Kai-iwi and Westmere Siltstone (lower part of photo) and the Kaikokopu Shell Grit is very sharp and marks the sequence boundary between Depositional Sequence 5 and 6. The Kaikokopu Shell Grit at this site is made up of large-scale planar cross-bedded pebbly shell conglomerate with intermittent wavy-bedded and streaky-laminated mud drapes and mega-flaser structures following bedding planes (Facies HE-1, Type A1 Shellbed).

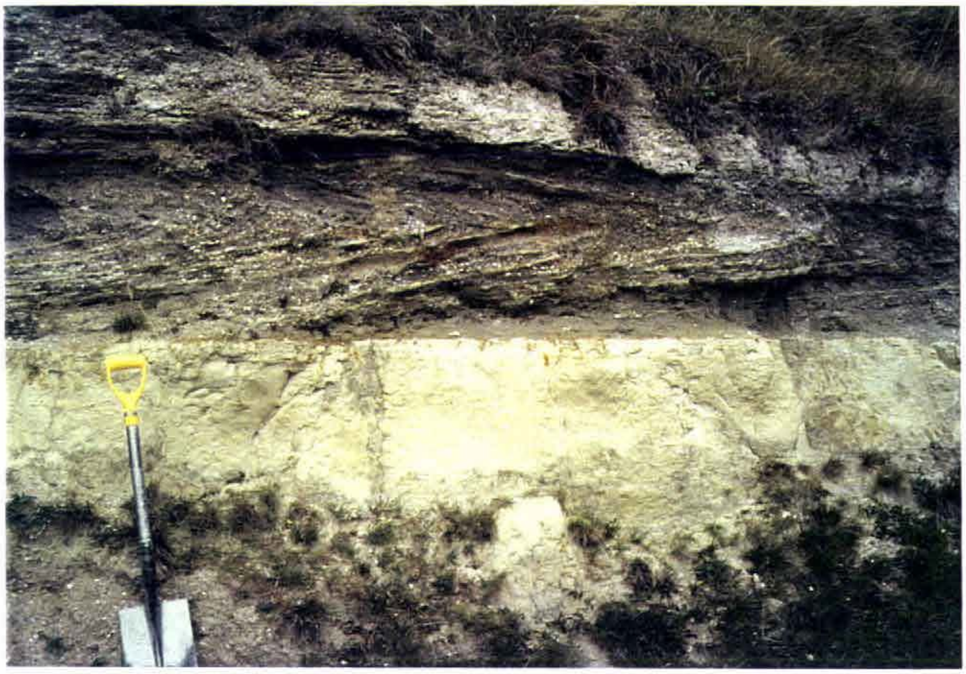
Plate 2.2.18 Close-up of the uppermost Kaikokopu Shell Grit member at S22/089323 (Plate 2.2.17). The strongly planar cross-bedded pebbly shell conglomerate of the Kaikokopu Shell Grit is overlain by a wavy-bedded unit (Facies HE-2) which may represent the base of a mud drape structure. An erosional surface which truncates the planar cross-beds is marked by a dashed black line.

Plate 2.2.17

Plate 2.2.18

Plate 2.2.19 Lower Kai-iwi and Westmere Siltstone/Kaikokopu Shell Grit contact at S22/086331 on a farm track between Morgans Road and Makuhou Road (closer to Makuhou Road). The very sharp, bored contact marks the sequence boundary between Depositional Sequence 5 and 6. The Kaikokopu Shell Grit at this site is distinctly herringbone cross-bedded and is made up of a pebbly shell conglomerate (Facies HE-1, Type A1 Shellbed).

Plate 2.2.20 Close-up of the contact between the Lower Kai-iwi/Westmere Siltstone and the Kaikokopu Shell Grit at S22/086331. The intertidal bivalve *Anchomasa (Barnea) similis* is preserved within burrows (Type C Shellbed) (35 mm lens cap for scale).



Herringbone cross-beds

Sequence Boundary

Plate 2.2.19

Sequence Boundary

Plate 2.2.20

Plate 2.2.21 Uppermost Kaikokopu Shell Grit at S22/069318 on Morgans Road, c. 300 m down valley from the farmhouse at the end of Morgans Road. Here the Kaikokopu Shell Grit is made up of fine sand with wavy and flaser bedding (Facies WS-2) (40 cm knife for scale).

Plate 2.2.22 Kaikokopu Shell Grit at S22/072306 on a farm track between Waimutu Road and Morgans Road. The formation at this site consists of low-angle planar cross-bedded and parallel-laminated fine sand with rare shelly, coarse sand lenses (Facies WS-2).

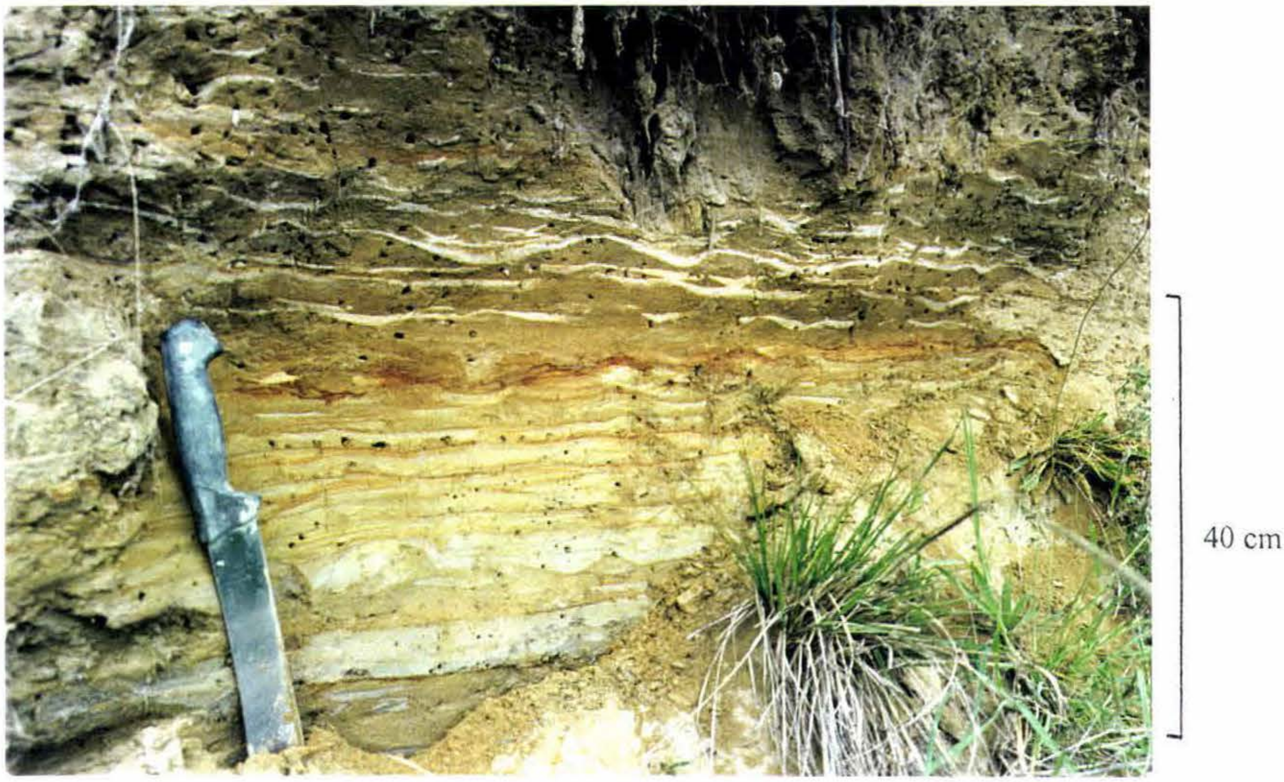


Plate 2.2.21

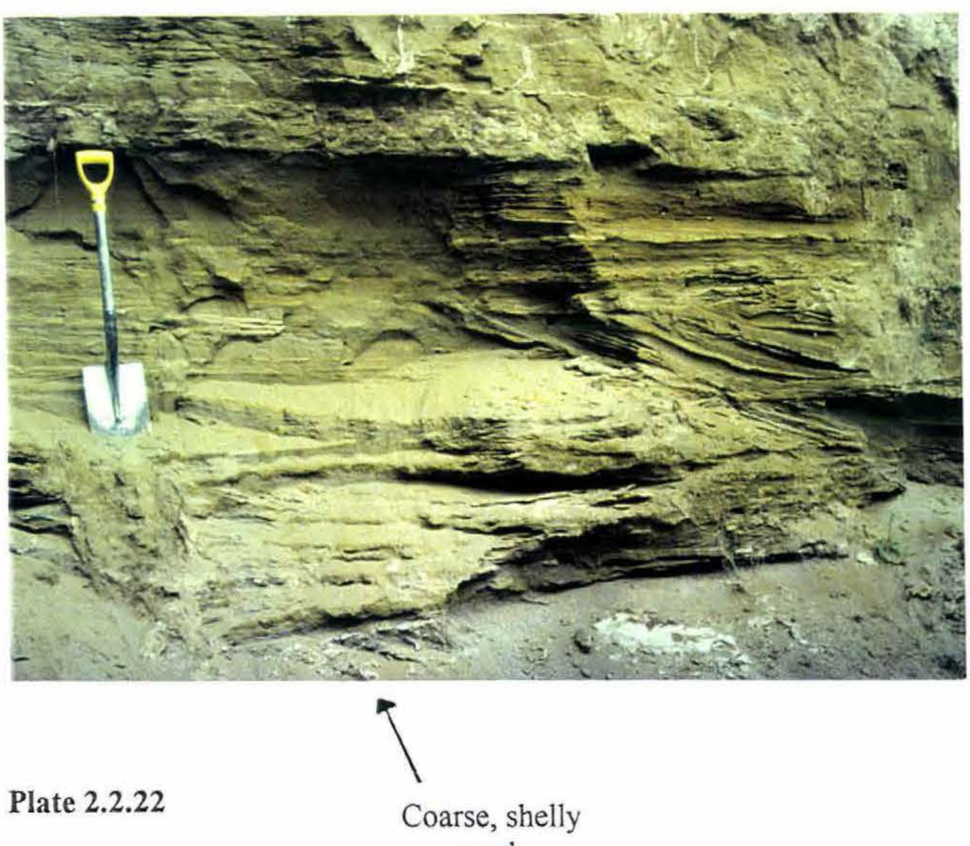


Plate 2.2.22

Morgans Shellbed (New)

Type Section : S22/092321 Farm track 1.7 km north-east from the homestead at the end of Morgans Road.

Name : named by the writer from outcrops of this shellbed near to Morgans Road.

Thickness : 1-3 m

Descriptive Sections :		
	S22/082320	Farm track, 1.5 km N of farm house at end of Morgans Road
	S22/083316	Outcrop on steep hillside (SE side) in first valley north of homestead at end of Morgans Road.
	S22/056323	Cliff face above Turakina River and off Turakina Valley Road, 200 m south of Morgans Road.

Descriptions

The Morgans Shellbed at all locations except S22/082320, is made up of a fine silty sand with abundant, diverse fauna (Facies TCS-1) and is approximately 1 m thick. The fauna are quite evenly distributed throughout the shellbed and the shellbed often has quite a high greywacke pebble content. At the type section, the shellbed lies upon the fossiliferous coarse silt deposit which is the uppermost unit of the Ruakina Formation. The contact between the two formations at the type section is quite sharp with little relief. The upper contact also is distinct and is overlain by massive blue-grey siltstone (Upper Westmere Siltstone in the Turakina section) **[Plate 2.2.23]**. Only 0.5 m of this siltstone is exposed and the entire section is included in **Figure 2.2.8**. The lower contact of the Morgans Shellbed at DS (S22/083316) is erosive with dm-scale relief. A flaser-bedded sandy unit underlies the shellbed at this site. The lower 0.3 m of the shellbed is extremely pebbly with few scattered fauna and with an abrupt transition into a muddy silty sand with abundant, diverse fauna **[Plate 2.2.24]**. The upper contact is again quite sharp with very little relief.

At DS (S22/082320) on a farm track 1 km north of the farm house at the end of Morgans Road, the majority of the exposed shellbed consists of a pebbly, shell conglomerate which is approximately 2.8 m thick. A 0.3 m muddy sand with abundant, scattered fauna overlies the conglomerate (Facies TCS-1). The pebbly, shell conglomerate overlies a coarse silt with few fossil fragments. The lithology is similar to the uppermost unit of the Ruakina Formation at S22/092321, 1.1 km SW of DS (S22/082320). The contact is very sharp with dm-scale relief. The upper contact of the shellbed was not exposed at this site.

The Morgans Shellbed at DS (S22/056323) at a cliff face above Turakina River, 200 m SW of the Morgans Road turnoff, consists of c. 1 m of muddy sand with abundant diverse fauna. The lower contact is sharp with cm-scale relief into a fossiliferous, loose sand. The upper contact was not exposed at this site.

The overall distribution of Depositional Sequence 6 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection sites :	S22/082320	(S22/ f 147a & b)
	S22/083316	(S22/ f 148)
	S22/092321	(S22/ f 149)
	S22/056323	(S22/ f 154b)

Several sculptured specimens of *Pecten kupei* were found within collection (S22/ f 148) and these appeared to be concentrated into a single thin band approximately 0.2-0.3 m below the upper contact. One small specimen of *Pecten kupei* was found in collection (S22/ f 147b). The occurrence of *P. kupei* places this formation within the Kupei Zone of Fleming (1957) **[Figure 2.1.5 and 6]**. The presence of *Stiracolpus waikopiroensis* and *Pelicaria* resembling *convexa* found in collection (S22/ f 149), are two species which are commonly associated with the Kupe Formation (Beu pers. comm., 1995) **[Table 2.2.3]**. The shellbed was initially thought to represent the Kupe Formation, however, it was found that the Upper Westmere Siltstone/Kupe Formation contact was slightly higher up in the sequence. An outcrop of this contact is clearly visible at a site on Turakina Valley Road (S22/060331) and the shellbed exposed at a cliff face south of this site at S22/056323, appears to be stratigraphically below this contact with the Kupe Formation.

Interpretation

The Morgans Shellbed forms the MCS for Depositional Sequence 6 in Turakina Valley. The facies of this shellbed represent deposition on the innermost shelf - inner shelf where sediment becomes increasingly scarce with the landward movement of the depocentre. The conglomerate may represent some tide/storm influence which reworked material from the innermost shelf environment (section 2.1.4c). The lower, quite sharp contact with the Ruakina Formation represents the Local Flooding Surface and the upper contact with the Upper Westmere Siltstone marks the Downlap Surface for Depositional Sequence 6.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) and on the correlations from Pillans (1994) (see **Figure 1.2**), the Morgans Shellbed is assigned to Oxygen Isotope Stage 19 and attributed an age of 760-770 Ka. The Morgans Shellbed can be correlated with the Upper Westmere Siltstone at Castlecliff although no Type B shellbed is represented there. No direct correlation to the Rangitikei Valley sequence exists (see **Figure 3.1**).

Table 2.2.3 : Palaeontology of the Morgans Shellbed in Turakina Valley

FAUNA	f147a	f147b	f148	f149	f154
Bivalvia					
Atrina pectinata zelandica			p	p	p
Carycorbula zelandica	p			s	s
Chlamys gemmulata	p		p		
Chlamys zelandiae			p	p	
Cyclomactra ovata	p				
Cyclomactra tristis					p
Dosinia zelandica			p	p	p
Felaniella (Zemysia) zelandica	p		s	p	
Glycymeris modesta	f			p	p
Kellia cycladiformis				f	
Leptomya retiaria				p	p
Myadora striata					p
Myadora subrostrata				f	
Nemocardium pulchellum				p	p
Notocallista multistriata				p	p
Oxyperas elongata			p		
Paphies n.sp.	p				
Paphies australis	p				
Paphies " mattua "					p
Pecten sp.				p	
Pecten kupei		p	s		
Pleuromeris zealandeae	s		p	c	s
Purpurocardia purpurata	f		f	f	s
Scalpomactra scalpellum	p			f	
Talochlamys gemmulata					p
Talochlamys zelandiae					p
Tawera spissa	a		s	a	a
Thracia vegrandis				p	
Tiostrea chilensis lutaria			p	f	p
Zemysia zelandica					s
Gastropoda					
Aeneator marshalli					p
Alcithoe sp.				p	
Alcithoe arabica			p		p
Alcithoe fusus					p
Amalda sp.				p	
Amalda (Baryspira) ? depressa	p				
Amalda (Baryspira) mucronata					p
Amalda (Gracilispira) novaezelandiae			p	p	p
Antimelatoma buchanani				p	p
Antisolarium egenum				s	
Aoteadrilla wanganuiensis	p				
Austrofusus glans			p		

Table 2.2.3 cont'd :

FAUNA - GASTROPODA CONT'D	f 147a	f 147b	f 148	f 149	f 154
Leucotina ambigua					p
Liracraea odhneri	p			s	f
Maoricolpus roseus	p		s	s	c
Michrelenchus sp.	p			p	
Michrelenchus ? sanguineus					s
Naticidae sp.				p	
Neoguraleus sp.	p			p	
Patelloida corticata					p
Pelicaria vermis				p	
Potamopyrgus antipodarum	p				
Seila sp.					p
Sigapatella novaezelandiae			p	p	s
Stiracolpus sp.					p
Stiracolpus aff. symmetricus	s		p	p	
Struthiolaria papulosa			p		
Trochus tiaratus			p	p	f
Uberella sp.					p
Xymene plebeius	c			p	
Xymene pusillus	f			p	p
Zeacolpus vittatus	p				p
Zegalerus tenuis	s			s	s
Zemitrella choava	p				
Zethalia zelandica	f				
Scaphopoda					
Antalis nana	f			s	p
Echinoidea					
Pseudechinus sp.					p
Brachiopoda					
Magasella sanguinea			p		
Waltonia inconspicua			p	p	f
Crustacea *(Callianassid)*				p	
Bryozoa	p				p

[Fauna identified by Alan Beu]

p = present
f = few
s = several
c = common
a = abundant

Plate 2.2.23 Morgans Shellbed at S22/092321 on a farm track between Morgans Road and Makuhou Road. The shellbed consists of muddy fine silty sand with abundant, diverse fauna and high pebble content (Facies TCS-1, Type B Shellbed). The upper contact is quite sharp and marks the Downlap Surface for Depositional Sequence 6. The Upper Westmere Siltstone overlies the shellbed (5 cm card for scale).

Plate 2.2.24 Morgans Shellbed at S22/083316 on a steep, north-facing hillside c. 1 km north of the farmhouse at the end of Morgans Road. At this site the lower contact of the shellbed is sharp and erosive with dm-scale relief into a fine, flaser - bedded sand. This lower contact marks the Local Flooding Surface for Depositional Sequence 6. The lower c. 0.4 m of the shellbed is very pebbly with few shells. The upper c. 1 m consists of a muddy, fine, silty sand with abundant, diverse fauna and high pebble content (Facies TCS-1, Type B Shellbed). The outcrop exposed here is 1.5 m thick.

Plate 2.2.23

Downlap Surface

Local Flooding Surface

Plate 2.2.24

1 m

Upper Westmere Siltstone

Type Section : Castlecliff section from Okehu Stream to 3 km south east of Omapu Stream.

Name : proposed by Fleming (1953) for his CL9 Upper Westmere Silts (1947a publication). The name is based on the Westmere Survey District.

Thickness : c. 10 m in Turakina Valley.

Reference Section : S22/060331 Turakina Valley Road; 750 m NE of Morgans Road.

Descriptive Sections : S22/051316 Small 'caves' by Turakina Valley Road
S22/057314 Farm between Waimutu Road and Morgans Road

Descriptions

Approximately 9-10 m of the Upper Westmere Siltstone is exposed at the reference section and is made up of massive blue-grey siltstone. The siltstone is unfossiliferous and very fine grained (Facies MZ-2). The upper contact is sharp with little relief and is overlain by a parallel-bedded, sandy unit thought to represent the basal member of the Kupe Formation at this location **[Plate 2.2.25]**.

At DS (S22/051316), where two small 'caves' are seen next to Turakina Valley Road, the very sharp upper contact with the pumiceous grit of the Kupe Formation is exposed. Underlying this contact is a 2 m coarse silt unit with a 0.3-0.4 m fossiliferous band which represents the upper part of the Upper Westmere Siltstone.

At DS (S22/057314) the Upper Westmere Siltstone consists of massive blue-grey siltstone with rare scattered fauna (Facies MZ-2).

Plate 2.2.25 Upper Westmere Siltstone/Kupe Formation contact at S22/060331 on Turakina Valley Road, c. 750 m north-east of the Morgans Road turnoff. The massive blue-grey Upper Westmere Siltstone (Facies MZ-2) is overlain by a parallel-bedded fine - medium sand which represents the Kupe Formation. The sharp contact (see dashed black line) marks the sequence boundary between Depositional Sequence 6 and 7.

Palaeontology

Stiracolpus sp. is the dominant faunal species observed within the Upper Westmere Siltstone. Fauna are scattered throughout parts of the formation at most of the sites described. A faunal collection was not made of the shelly band observed at the top of the Upper Westmere Siltstone at DS (S22/051316)

Interpretation

The Upper Westmere Siltstone comprises the HST for Depositional Sequence 6 in the Wanganui Basin, Castlecliffian sequence.

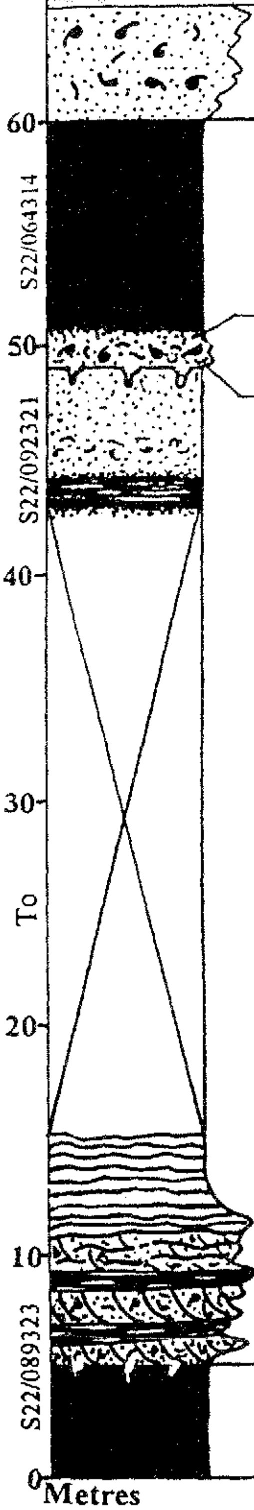
Facies of the Upper Westmere Siltstone indicate deposition on the inner and inner - middle shelf (section 2.1.4d) where at times, sedimentation rates were low enough to allow faunal activity.

Age and Correlation

Abbott and Carter (1994) and Pillans (1994) assigned the Upper Westmere Siltstone to Oxygen Isotope Stage 19 (c. 770 Ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) (see **Figure 1.2**).

The thickness of the formation increases from 17 m at Wanganui coast (Fleming, 1953; Abbott and Carter, 1994; Abbott, 1994) to c. 47 m in Turakina Valley if the Ruakina Formation (excluding the Kaikokopu Shell Grit) and the Morgans Shellbed are also taken into account. However, because there is a clear distinction between these units in Turakina Valley, the Upper Westmere Siltstone formation was relegated to the top c. 10 m of fossiliferous, blue-grey siltstone which overlies the Morgans Shellbed.

The Rangitikei correlative is most likely the units between the Kaikokopu Shellbed and the Waiomio Formation. (Abbott, 1994) (see **Figure 3.1**).



Stratigraphic Column	Descriptions	Facies Type	Interpretation	Seq. Strat.	Formation	
	Pebbly, shell conglom. with trough cross beds Fine tephric sand	HE-1 HE-4	Tide/storm dom.'d innermost shelf	TST	Kupe Formation	DS 7
	Sequence Boundary Massive, fossiliferous blue-grey siltstone	MZ-2	Inner - middle shelf	HST	Upper Westmere Siltstone	DS 6
	Muddy fine sand with abundant fauna	TCS-1	Innermost shelf	MCS	Morgans Shellbed	
	Coarse silt with a band of scattered fauna including *Pecten* (FAD) Streaky-laminated siltstone	ZS-2 HE-3	Shoreface - shelf transition Tide/storm dominated innermost shelf	TST	Ruakina Formation	
	Wavy-bedded fine sand Large-scale planar cross-bedded pebbly shell conglomerate with mud drapes and mega-flasers (Type A1 Shellbed)	HE-2 HE-1	Tide/storm dominated innermost shelf	TST	*Kaikokopu Shell Grit	
	Sequence Boundary Massive blue-grey siltstone	MZ-2	Inner -middle shelf	HST	L. Westmere Siltstone	DS 5

Figure 2.2.8 Stratigraphic summary diagram for Depositional Sequence 6 in Turakina Valley from sites S22/089323 - 092321 between Morgans Road and Makuhou Road and from site S22/064314 between Waimutu Road and Morgans Road (See map and cross-section at the back of this thesis).

* The Kaikokopu Shell Grit is the basal member of the Ruakina Formation.

2.2.8 Depositional Sequence 7

Kupe Formation

Type Section : Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream.

Name : proposed by Fleming (1947a) for beds in the Wanganui coastal section which contained the first appearance of *Pecten kupei*.

Thickness : 3 - 6 m in Turakina Valley

Reference Section : S22/064314 Farm to SE of Turakina Valley Road (between Waimutu Road and Morgans Road). Small outcrop above stream bed, and across from a well marked farm track (see map at end of thesis).

Descriptive Sections : S22/071309 As for reference section but farther up farm track.

S22/061311 Cliff face up eastern tributary on farm between Waimutu and Morgans Road.

S22/05136 Small 'caves' by Turakina Valley Road.

Descriptions

The Kupe Formation at the reference section lies unconformably upon the wave - planed surface of the Upper Westmere Siltstone. The formation consists of 2m of fine, white, tephric, well - sorted sand **(sample S22, Appendix B)** with faint convolute deformation structures (Facies HE-4) **[Plate 2.2.26]**. The volcanic glass in this unit was identified as the Kupe Tephra by Pillans (Pillans pers. comm., 1994).

Overlying this is a 50 - 100 mm pumiceous grit **(sample T10, Appendix A)**, which is faintly trough cross-bedded on a small scale and which grades into at least 5 m of fine-medium shelly sand (Facies HE-1) (S22/ f 151, **Table 2.2.4**). The upper contact with the Upper Kai-iwi Siltstone is obscured. This section is summarised in **Figure 2.2.9**. Farther up the valley at DS (S22/071309), the shellbed is represented by an unfossiliferous clast supported, pebbly sand. This conglomerate sharply overlies the fine, tephric sand member.

The Kupe Formation is again exposed in a cliff face at DS (S22/061311) on the farm between Waimutu Road and Morgans Road. Approximately 5 m of the formation is exposed here. The lowermost 2 m consists of cm - scale interbedded, wavy-bedded silt and medium, often small-scale planar cross - bedded, pumiceous sand (Facies HE-2). Pumice taken from the sand members **(sample T11, Appendix A)** was found to be chemically similar to the Kaukatea Ash but also showed a close similarity to Sample **T10** which was identified as the Kupe Tephra. However, when plotted on a ternary diagram (**Appendix A**), **T11** lies in a position consistent with that of the Kaukatea Ash and is most likely a reworked product of that eruptive event. This pumiceous unit grades over 10-20 mm into a coarse, faintly trough cross-bedded, sand with abundant scattered fauna (Facies HE-1, Type A1 Shellbed). Approximately 3 m of the shellbed is exposed at this site **[Plate 2.2.27]**. The lower contact with the Upper Westmere Siltstone and the upper contact with the Upper Kai-iwi Siltstone, are not exposed at this location. The lower contact was exposed at DS (S22/051316) beside two small 'caves' just off Turakina Valley Road and between Waimutu Road and Morgans Road. The contact is very sharp with little relief and is overlain by 50-100 mm of pumiceous grit similar to that seen at the reference section. At this site, the contact with the pumiceous grit represents the lower sequence boundary, whereas at the reference section, the pumiceous grit lies 2-3 m above the sequence boundary. The overall distribution of Depositional Sequence 7 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection Sites : S22/061311 (S22/ f 143)

S22/064314 (S22/ f 151) **(see Table 2.2.4)**

Interpretation

The Kupe Formation forms the TST of Depositional Sequence 7 in the Wanganui Basin, Pleistocene sequence. A MCS is not evident in this depositional sequence and indicates that complete sediment starvation never occurred.

The Kupe Formation is represented by heterolithic facies in Turakina Valley indicating deposition on a tide/storm dominated, innermost shelf (section 2.1.4b). The presence of the fine, white, tephric sand at the reference section seems to be a local feature and is interpreted to have been deposited in the lowermost shoreface or shoreface-shelf transition. Deposition of this member followed an eruption sourced in the Central North Island and the deformation structures indicate rapid deposition.

Age and Correlation

A fission - track age of 450 Ka was attributed to the Kupe Tephra from pumice found within the coeval Waiomio Shellbed in Rangitikei Valley (Seward, 1974, 1976). Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990), Abbott and Carter (1994) and Pillans (1994) assigned the Kupe Formation to Oxygen Isotope Stage 17 and attributed an age of c. 700 Ka (see **Figure 1.2**).

Facies of the Kupe Formation change markedly across the basin. The individual members seen at the Castlecliff section (Fleming, 1953) are not evident in Whangaehu Valley (Woolfe, 1987) or in Turakina Valley (this work). East of Wanganui the formation seems to be increasingly represented by a shell conglomerate. The thickness of the formation across the basin increases slightly towards the east. Woolfe (1987) reported a thickness of 16 m on the Whangaehu/Turakina interfluve, 10 m thicker than on the coast. He describes the formation as "richly fossiliferous, pebbly sand and silt", probably similar in nature to DS (S22/061311) in an eastern tributary of the Turakina River between Waimutu Road and Morgans Road (see **Figure 3.1**).

Table 2.2.4 : Palaeontology of the Kupe Formation in Turakina Valley

FAUNA	f143	f151
Bivalvia		
Carycorbula zelandica	s	f
Dosinia zelandica		p
Felaniella (Zemysia) zelandica	f	
Glycymeris modesta	s	f
Limaria orientalis		p
Myadora striata	p	f
Myadora subrostrata	p	
Nemocardium pulchellum		p
Notocallista multistriata		p
Paphies n.sp.	p	
Paphies australis	p	s
Paphies " tuatua "		c
Pleuromeris zealandica	s	s
Purpurocardia purpurata	s	s
Serratina charlottae		p
Spisula aequilatera	p	
Talochlamys gemmulata		p
Tawera spissa	c	c
Tiostrea chilensis lutaria	p	c
Zemysia zelandica		c
Gastropoda		
Alcithoe sp.		
Alcithoe arabica	p	p
Alcithoe fusus		p
Amalda (Baryspira) mucronata	p	p
Amalda (Gracilispira) novaezelandiae	p	s
Antimelatoma buchanani	p	
Antisolarium egenum	f	f
Buccinulum sp.	f	
Cominella sp.	p	
Leucotina ambigua	p	s
Maoricolpus roseus	p	c
Michrelenchus sp.	s	
Michrelenchus ? sanguineus		f
Neoguraleus sp.	f	
Odostomia sp.	p	
Pelicaria vermis		p
Penion sp.		p
Proxiuber sp.		p
Seila sp.		p
Sigapatella novaezelandiae		p

Table 2.2.4 cont'd :

FAUNA - GASTROPODA CONT'D	f 143	f 151
Stiracolpus sp.		f
Stiracolpus aff. symmetricus	p	
Trochus tiaratus	p	p
Uberella sp.	p	
Xymene plebeius	c	c
Xymene pusillus	p	
? Zafra aff. impedita	p	
Zeacumantus lutulentus	p	
Zegalerus tenuis	s	s
Zemitrella choava	f	
Zethalia zelandica	f	p
Scaphopoda		
Antalis nana	p	
Brachiopoda		
Waltonia inconspicua		p
Bryozoa	s	p

[Fauna identified by Alan Beu]

p = present
f = few
s = several
c = common
a = abundant

Plate 2.2.26 Kupe Formation (Tephra) at S22/064314; a small outcrop along an eastern tributary of the Turakina River, between Waimutu Road and Morgans Road. A fine, tephric sand (Kupe Tephra) (Facies HE-4) is sharply overlain by a faintly small-scale trough cross-bedded pumiceous grit (sample T10). Spade is approximately 1 m in length.

Plate 2.2.27 Kupe Formation at S22/061311; a cliff face up an eastern tributary of the Turakina River between Waimutu Road and Morgans Road. The lower half of the outcrop is made up of cm-scale interbedded, wavy-bedded silt and fine pumiceous sand (sample T11) with small-scale planar cross-beds (Facies HE-2). The upper half of the outcrop consists of 2.5-3 m of coarse faintly trough cross-bedded sand with abundant, scattered fauna (Facies HE-1, Type A1 Shellbed). The outcrop is approximately 7 m thick.

T 10

Plate 2.2.26

Convolute deformation

Plate 2.2.27

shellbed

T 11

Upper Kai-iwi Siltstone

Type Section : Castlecliff section from Okehu Stream to 3 km south-east of Omapu Stream.

Name : proposed by Fleming (1953) for the " Kai-iwi Blue Clays " of Park (1887).

Thickness : c. 30 m in Turakina Valley.

Reference Section: S22/066315 Outcrop on hillside across from farm track, 1 km south of Morgans Road, following an eastern tributary of the Turakina River. Farm track is clearly marked on the map at the back of this thesis.

Descriptions

Approximately 20 m of the Upper Kai-iwi Siltstone is exposed in Turakina Valley. The entire thickness extends to 30 m **(Appendix D)**. Where exposed, the formation appears as a massive, barren, blue-grey siltstone (Facies MZ-2). The lower contact with the Kupe Formation is obscured. The upper contact with the Seafield Sand is sharp and undulating (cm - scale), with no sign of boring by *Anchomasa (Barnea) similis* along the contact. This section is summarised in Figure 2.2.9 and the overall distribution of Depositional Sequence 7 is shown on the map and cross - section at the end of this thesis.

Palaeontology

No macrofauna observed

Interpretation

The Upper Kai-iwi Siltstone forms the HST for Depositional Sequence 7 in the Wanganui Basin, Pleistocene sequence. Facies indicate deposition below wave base on the inner - middle shelf (section 2.1.4d). The sharp upper contact marks the upper sequence boundary between Depositional Sequences 7 and 8.

Age and Correlation

Abbott and Carter (1994) and Pillans (1994) place the Upper Kai-iwi Siltstone within Oxygen Isotope Stage 17 based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) and attributed an age of c. 680-700 Ka to the formation (see **Figure 1.2**). In Rangitikei Valley, the formation is correlated with the Reu Reu Formation of Abbott (1992). Pillans (1994) correlates the Upper Kai-iwi Siltstone with the Shell Creek Fossil Beds in Rangitikei Valley (see **Figure 3.1**).

The formation thickens quite markedly from Castlecliff where the formation is 9 m thick (Fleming, 1953) to Rangitikei Valley where the thickness has increased to c. 30 m (Abbott, 1994). Woolfe (1987) recorded a thickness of 45 m in Whangaehu Valley (see **Figure 3.1**). The facies generally change very little, although, Fleming reported the presence of scattered fauna throughout the formation at Castlecliff.

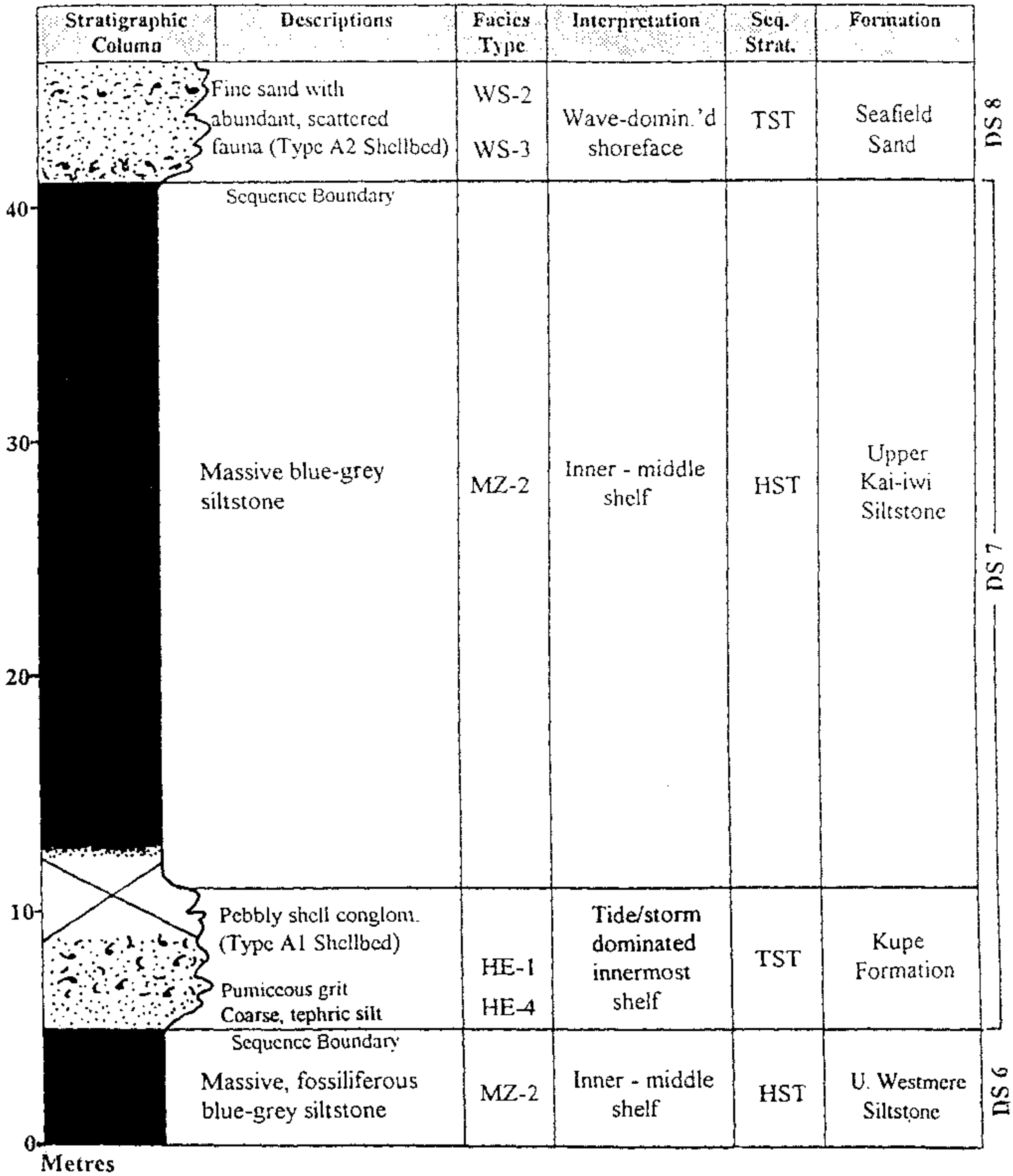


Figure 2.2.9 Stratigraphic summary diagram for Depositional Sequence 7 in Turakina Valley from site S22/064314 - 066315 between Waimutu Road and Morgans Road (See map and cross-section at the back of this thesis).

2.2.9 Depositional Sequence 8

Seafield Sand

Type Section : Castlecliff section, approximately 3 km south-east of Omapu Stream.

Name : name given by Fleming (1953) after the Seafield Trig Station near the Castlecliff coastline.

Thickness : up to 25 m in Turakina Valley

Reference Section : S23/082296 - S23/073302 Farm track following tributary down valley on farm at end of Howie Road.

Descriptive Sections :

S23/073302	Farm track 1.8 km down main valley at the end of Howie Road
S23/082296	Farm track 0.7 km down main valley at the end of Howie Road
S23/077300	Cliff face above stream 1.5 km down main valley from the end of Howie Road.
S22/066315	Hillside across from farm track between Waimutu Road and Morgans Road
S22/071308	Farm track towards head of valley between Waimutu Road and Morgans Road

Descriptions

The most complete exposure of the Seafield Sand in Turakina Valley occurs in an eastern tributary of the Turakina River on the farm at the end of Howie Road. Due to the extent of outcrop exposed, this has been designated as the reference section for the study area. Here the contact between the Upper Kai-iwi Siltstone and the Seafield Sand is a sharp, wave-planed surface **[Plate 2.2.28]**. Approximately 10 m of loose, brown, wavy-bedded, fine-medium sand unconformably overlies this contact. In places, the sand component between mud beds becomes quite coarse, with indistinct small-scale planar cross beds. This sandy phase, (Facies WS-2), grades into a wavy to lenticular-bedded and streaky-laminated siltstone (Facies HE-3) **[Plate 2.2.29]**. Approximately 3 m of this bedded siltstone is exposed at DS (S23/073302) on the farm track c. 1.8 km down the main valley on the farm at the end of Howie Road, and was again observed at DS (S23/082296) up valley, on the same farm track . The total thickness of this unit is estimated to be 15 m **(Appendix D)**. The entire section is summarised in **Figure 2.2.10**.

An outcrop of the Seafield Sand at DS (S22/066315) on a farm between Waimutu Road and Morgans Road, displays a fine sandy shellbed (Facies WS-3) containing many *Pecten marwicki* **(sample f 141, Table 2.2.5)**, located 1.5 m above the wave-planed surface of the Upper Kai-iwi Siltstone **[Plate 2.2.30]**. The shellbed resembles the Type A2 Shellbed of Abbott and Carter (1994). The same shellbed was again located at DS (S22/071308) up valley from DS (S22/066315). Approximately 5 m above this shellbed, a loose, fine-medium sand containing abundant *Tawera spissa* occurs (Type A2 Shellbed), **(sample f 142b, Table 2.2.5)**.

The overall distribution of Depositional Sequence 8 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

<u>Palaeontology</u>

Collection sites : S22/066315 (S22/ f 141)
S22/ 071308 (S22/ f 142a & 142b)

The shellbed at DS (S22/066315) on a farm between Waimutu Road and Morgans Road, is the first recorded occurrence of a shellbed at the base of the Seafield sand. The shellbed contains abundant *Pecten marwicki* **[Table 2.2.5]**, which places the base of the Lower Marwicki Zone at the lower contact of the Seafield Sand in Turakina Valley (see

Figure 3.2). Fleming (1957) placed the base of the Lower Marwicki Zone in the middle of the Seafield Sand (see **Figure 2.1.6**).

Interpretation

The Seafield Sand forms the TST of Depositional Sequence 8 in the Pleistocene Wanganui Basin sediments.

The Seafield Sand was deposited after the Upper Kai-iwi Siltstone was wave planed by the ensuing transgression. The erosional unconformity represents the lower sequence boundary for Depositional Sequence 8.

The thick basal unit of sand directly overlying the sequence boundary indicates deposition in a shallow intertidal shoreface environment (section 2.1.4a). The faunal assemblages of lag deposits found at DS (S22/066315 and S22/071308, S22/ f141, f142a) on the farm between Waimutu Road and Morgans Road, suggests deposition in shallow water (c. 5-10 m) on an open coast, not far off a sandy beach. The presence of *Purpurocardia* and *Tucetona sp.* in sample S22/ f 142a , probably indicate a tidal channel was in existence near by (Beu pers. comm., 1995). The shellbed located above this (S22/ f142b), has a very shallow water fauna i.e. 90 % of sample was made up *Tawera spissa*. Deposition in a quiet environment such as a bay-mouth bar or similar is indicated here. The faunal assemblage is quite unusual when compared to other Wanganui-type shellbeds (Beu pers. comm., 1995). The shallowing trend from one shellbed to the next at DS (S22/071308), may indicate that uplift on the Marton Anticline was occurring at this point in time. An alternative interpretation may be that rapid sedimentation caused a decrease in accommodation resulting in deposition of progressively shallower water facies. A third cause of this shallowing trend may be that sea-level decreased for a time.

Much of the Seafield Sand in Turakina Valley is made up of small - scale heterolithic facies (Facies HE-2 and HE-3) and this is attributed to either uplift along the upper flank of the Marton Anticline or that a major sediment source was diverted to this part of the basin (see section 3.2).

Age and Correlation

Abbott and Carter (1994) and Pillans (1994) assigned the Seafield Sand to Oxygen Isotope Stage 15 (c. 610 Ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) (see **Figure 1.2**).

The basal Toms Conglomerate member of the Seafield Sand at Castlecliff and in Rangitikei Valley (Potter, 1984) is missing in Turakina Valley, although the lower shellbed of the Seafield Sand in Turakina Valley at S22/066315 is correlated with the Toms Shellbeds.

The formation decreases in thickness across the basin from 30 m at Castlecliff (Fleming, 1953) to 25 m in Turakina Valley. In Rangitikei Valley, the coeval Toms Conglomerate is approximately 7 m thick (Abbott, 1994) (see **Figure 3.1**). The basal facies of the formation at Castlecliff and Rangitikei Valley represent deposition on a tide/storm dominated innermost shelf, while the formation in Turakina Valley initially represents shallower deposition on a wave - dominated shoreface and then deposition on the innermost shelf.

Table 2.2.5 : Palaeontology of the Seafield Sand in the Turakina Valley

FAUNA	f 141	f 142a	f 142b
Bivalvia			
Austrovenus stutchburyi	p		
Barbatia novaezelandiae		p	
Carycorbula zelandica		p	p
Chlamys gemmulata	c	s	
Dosinia sp.			s
Dosinia (Phacosoma) subrosea	p		f
Ellptotellina urinata			s
Felaniella (Zemysia) zelandica	p		f
Gari sp.			p
Gari hodgei		p	
Glycymeris modesta		p	s
Gonimyrtea concinna		s	
Kellia cycladiformis			p
Modiolarca impacta	p	p	
Myadora striata	p	c	
Myadora ? subrostrata			s
Nemocardium (Pratulum) pulchellum	p		
Notocallista multistriata		s	
Nucula nitidula		s	f
Paphies sp.	p		
Pecten benedictus marwicki	s	s	
Pleuromeris zealandica		s	
Purpurocardia purpurata	s	c	p
Scalpomactra scalpellum	p	p	s
Tawera spissa	p	s	sa
Tiostrea chilensis lutaria	p	c	p
Tucetona laticostata		p	
Gastropoda			
Alcithoe arabica	p	p	
Antimelatoma buchanani	p	p	
Antisolarium egenum	p	a	s
Amalda (Baryspira) ? depressa			p
Amalda (Baryspira) mucronata	s		
Austrofusus glans	s		
Buccinulum linea	p		
Cominella sp.	p		
Cominella (Josepha) glandiformis		p	
Glaphyrina caudata		p	
Leucotina ambigua		p	
Maoricolpus roseus	a	c	f
Michrelenchus sp.			f
Neoguraleus ? amoenus		p	

Table 2.2.5 cont'd

FAUNA - GASTROPODA CONT'D.	f 141	f 142a	f 142b
Notoacmea sp.			p
Penion cuvierianus	p		
Poirieria zelandica	s	p	
Stiracolpus aff. symetricus		s	
Stiracolpus cf. blacki	p		
Tanea zelandica	p		
Trochus tiaratus	p		
Uberella denticulifera		p	
Xymene bonnetti	p	p	
Xymene plebeius		p	
Xymene pusillus		p	
Zeacolpus vittatus	p		
Zegalerus tenuis	p	p	s
Zemitrella choava			p
Zethalia zelandica	p		p
Crustacea, Brachyura			
Hermit crab claw	p		
Bryozoans (Stick and Button-shaped)		p	a

[Fauna identified by Alan Beu]

p = present **c = common**

f = few **a = abundant**

s = several **sa = super abundant**

Plate 2.2.28 Upper Kai-iwi Siltstone/Seafield Sand contact at S23/077300, 1.5 km down valley from the end of Howie Road. The sharp contact (dashed line along hillside) represents the sequence boundary between Depositional Sequences 7 and 8.

Plate 2.2.29 The lowermost silt unit of the Seafield Sand at S23/073302 on a farm track c. 1.5 km down valley from the end of Howie Road. At this site the siltstone is lenticular-bedded and streaky-laminated (Facies BZ-2 or HE-3) Spade is approximately 1 m in length.

Plate 2.2.28

Plate 2.2.29

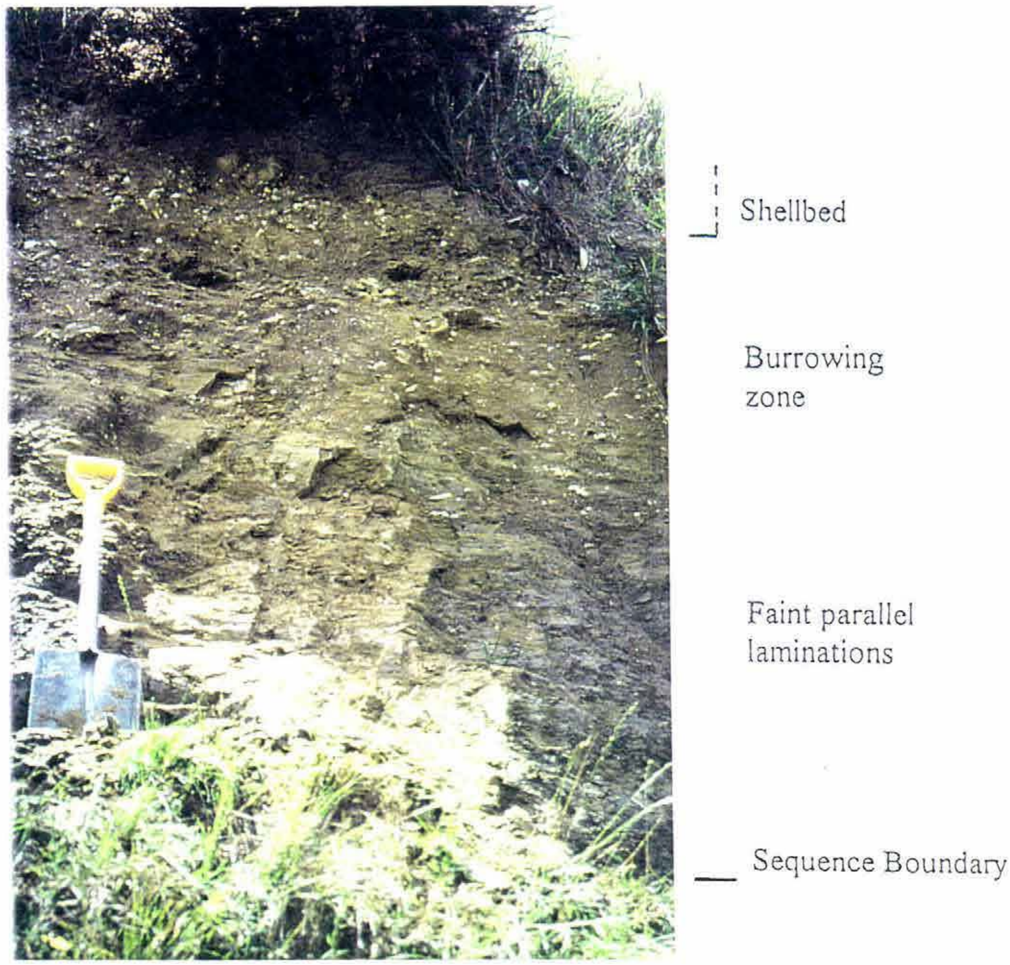


Plate 2.2.30 Lowermost shellbed within the Seafield Sand at S22/066315 on a south-facing hillside in an eastern tributary of the Turakina River between Waimutu Road and Morgans Road. The spade rests on the contact with the Upper Kai-iwi Siltstone. Above the contact, faintly parallel-laminated fine sand (Facies WS-3) is overlain by a shellbed of similar lithology (Type A2 Shellbed). The spade is approximately 1 m in length.

Howie Shellbed (New)

Type Section : S23/082296 Farm track down main valley at the end of Howie Road

Name : Named from the Howie Road section which extends down valley from the end of the road.

Thickness : c. 1.5 m

Descriptions :

At the type section on the farm track down the main valley at the end of Howie Road, a conglomeratic shellbed (Facies TCS-1), c. 1 m thick, unconformably overlies the uppermost siltstone unit of the Seafield Sand (Facies HE-3). A muddy sand with abundant, scattered fauna (Type B Shellbed , Facies TCS-1), c. 0.5 m, overlies the conglomeratic shellbed **[Plate 2.2.31]**. The upper contact of the shellbed is not exposed.

Palaeontology

Collection sites : S23/082296 (S23/ f 88)
S23/079300 (S23/ f 90)

At DS (S23/082296), 0.7 km on a farm track down valley from the end of Howie Road, one specimen of *Pecten kupei* was found within the Type B Shellbed and was most likely reworked from the underlying Kupe Formation or Morgans Shellbed. The base of the Lower Marwicki Zone is placed at the lower contact of the Seafield Sand in Turakina Valley (see **Figure 3.2**) whereas Fleming (1957), placed it in the middle of the Seafield Sand formation (see **Figure 2.1.6**).

Interpretation

The Howie Shellbed makes up the Mid-cycle shellbed for Depositional Sequence 8 in the Turakina Valley Pleistocene sequence. The pebbly part of the shellbed (section 2.1.4c) seen at DS (S23/082296) has a shallow-water assemblage. The fauna are highly abraded, suggesting reworking and transportation into this environment. The very erosive lower contact of this shellbed marks the position of the Local Flooding Surface. The muddy, fossiliferous, fine sand overlying this has a deeper-water fauna (c. 20-30 m). Generally, the assemblage resembles that of the Tainui Shellbed and Lower Castlecliff Shellbed at Castlecliff. However, the presence of *Glaphyrina* and *Poirieria* give the assemblage a more offshore appearance (Beu pers. comm., 1995). The nature of this shellbed indicates deposition on a starved inner-shelf (section 2.1.4c).

Age and Correlation

The Howie Shellbed is placed within Oxygen Isotope Stage 15 based on the correlations of Pillans (1994) using the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990) (see **Figure 1.2**).

The occurrence of a Type B Shellbed in this stratigraphic position appears to be restricted to Turakina Valley. The nature of the stratigraphy in this position in Rangitikei Valley is not well known (see **Figure 3.1**) and a correlative shellbed may exist there, but has never been documented.

Table 2.2.6 : Palaeontology of the Howie Shellbed in the Turakina Valley

FAUNA	f88	f90
Bivalvia		
Carycorbula zelandica	p	s
Glycymeris sp.		p
Glycymeris modesta	s	
Gonimyrtea concinna		p
Limatula maoria		p
Myadora striata		s
Paphies n. sp.	p	
Pleuromeris zealandica	p	s
Purpurocardia purpurata		s
Talochlamys gemmulata		s
Tawera spissa	s	s
Tucetona laticostata		s
Zemysia zelandica		p
Zemysina globus		p
Gastropoda		
Alcithoe arabica	p	
Antisolarium egenum		s
Amalda (Baryspira) sp.	p	
Amalda (Baryspira) mucronata		p
Ataxocerithium huttoni		p
Austrofusus glans		s
Buccinulum sp.	p	
Buccinulum linea		p
Cabestana tabulata		p
Callistoma ? pellucida		p
Glaphyrina caudata		p
Leucotina ambigua	p	s
Maoricolpus roseus		c
Michrelenchus ? sanguineus		c
Microvoluta biconica		p
Poirieria zelandica		s
Seila sp.		p
Stiracolpus sp.	p	
Stiracolpus ? delli		s

Table 2.2.6 cont'd

FAUNA - GASTROPODA CONT'D.	**f88**	**f90**
Struthiolaria papulosa		p
Tanea zelandica		s
Trochus tiaratus		p
Xymene sp.	p	
Xymene bonnetti		p
Zeacolpus vittatus		p
Zethalia zelandica	f	
Bryozoans (Stick and Button-shaped)	p	p

[Fauna identified by Alan Beu]

p = present **c = common**

f = few **a = abundant**

s = several **sa = super abundant**

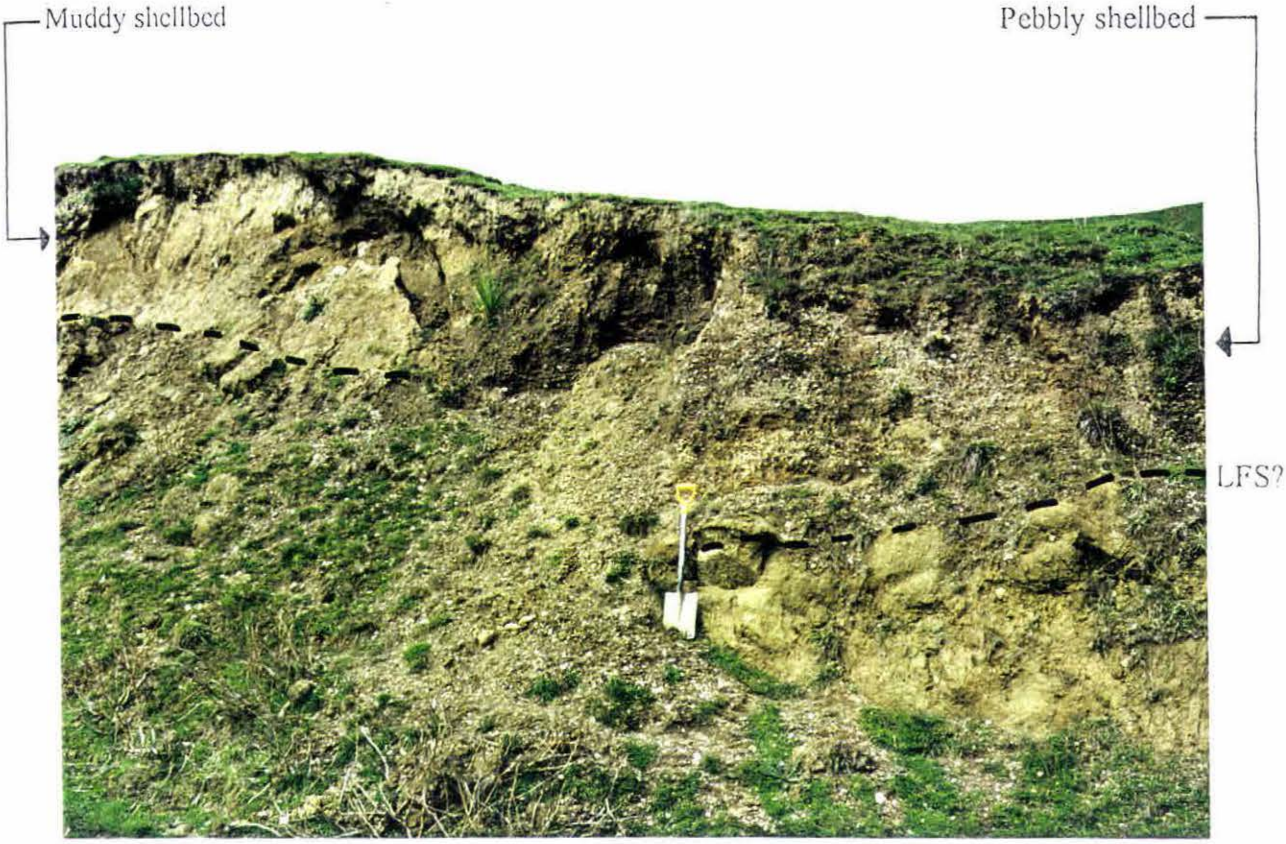


Plate 2.2.31 Howie Shellbed at S23/082296 on a farm track c. 0.7 km down valley from the end of Howie Road. The lower contact, visible just below the spade handle, is erosive with dm-scale relief and represents the Local Flooding Surface for Depositional Sequence 8. Approximately 1-1.5 m of very pebbly sand with scattered shells overlies the contact (Facies TCS-1, Type B Shellbed). A muddy fine sand with scattered fauna (Facies TCS-1), c. 0.5-1 m thick, overlies the pebbly unit. The upper contact of this shellbed was not exposed at this site. The spade is approximately 1 m in length.

Lower Castlecliff Siltstone (LCZst) and Shellbed (LCSb)

Type Section : Castlecliff section, c. 3 km south-east of Omapu Stream.

Name : The name 'Lower Castlecliff Siltstone' was proposed for a siltstone unit above the Lower Castlecliff Shellbed at Castlecliff (Abbott and Carter, 1994). This formation was not described by Fleming (1953). The Lower Castlecliff Shellbed was named by Fleming (1953) for the basal shellbed of the '*Antisolarium* Sands' at Castlecliff (Fleming, 1947a). The Lower Castlecliff Shellbed strongly resembles the Upper Castlecliff Shellbed at Castlecliff in its lithology and fauna, and the name was chosen to highlight this similarity.

Thickness : 20 - 25 m exposed in Turakina Valley. Exact thickness is unknown due to incomplete exposure of outcrop. The Lower Castlecliff Shellbed is 0.1 - 0.3 m in Turakina Valley.

Reference Section : S23/086294 Farm track, 0.4 - 0.7 km down valley from the end of Howie Road.

Descriptive Section : S23/056301 Farm track off Waimutu Road leading up to quarry (LCZst).

S23/082296 Small valley off farm track at the end of Howie Road (LCSb).

S23/080302 Small outcrop on hillside above farm track at the end of Howie Road (LCSb).

Descriptions

Approximately 5 - 7 m of the section above the Howie Shellbed is obscured. The overlying barren, muddy siltstone (Facies BZ-2) appears bedded on a dm-scale and is approximately 8 m thick. The bedded siltstone member grades into a massive, barren, blue-grey siltstone (Facies MZ-2) which is 5-7 m thick.

The Lower Castlecliff Shellbed overlies this massive and bedded siltstone unit and is a thin (0.1-0.3 m) muddy, fine, silty sand, with abundant, diverse fauna (Facies TCS-2, Type B Shellbed) at the reference section and both descriptive sections. The lower contact is sharp and undulating on a cm - dm scale **[Plate 2.2.32]**. Burrowing into the upper siltstone member of the Seafield Sand is extensive at both descriptive sections **[Plate 2.2.33]**. The upper contact with the Lower Castlecliff Siltstone is also sharp **[Plate 2.2.32]**.

An additional unit of the Lower Castlecliff Siltstone overlies the Lower Castlecliff Shellbed at the reference section i.e. the Lower Castlecliff Shellbed forms part of the Lower Castlecliff Siltstone. This overlying unit consist of an unfossiliferous lenticular-bedded to streaky-laminated, muddy siltstone (Facies BZ-2 or HE-3), unconformably overlying the Lower Castlecliff Shellbed **[Plate 2.2.32 and 2.2.34]**. The entire section is summarised in **Figure 2.2.10**.

The Lower Castlecliff Siltstone is similar in appearance at its descriptive section, but with a more blue-grey colour. At this location only c. 1.5 m of the formation is exposed and the upper contact with the Pinnacle Sand is obscured. Therefore, in Turakina Valley the upper contact of the Lower Castlecliff Siltstone was nowhere observed.

The overall distribution of Depositional Sequence 8 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection sites: S23/085294 (S23/ f 85)
S23/080302 (S23/ f 89)

The presence of *Pecten marwicki* **(Table 2.2.7)** within the Lower Castlecliff Shellbed, places the formation within the Lower Marwicki Zone for the Turakina Valley section (see **Figure 3.2** and **Figure 2.1.6**).

The exposed sections of the Lower Castlecliff Siltstone were devoid of macrofossils.

Interpretation

The Lower Castlecliff Siltstone and Shellbed represent the HST of Depositional Sequence 8 in the Turakina Valley sequence.

Facies of the Lower Castlecliff Siltstone that lie below the Lower Castlecliff Shellbed indicate deposition on the inner shelf below storm wave base. Preservation of primary bedding, probably suggests a high rate of sedimentation inhibiting biological activity..

The Lower Castlecliff Shellbed represents a second occurrence of a MCS within Depositional Sequence 8 in the Turakina Valley sequence and may indicate sedimentation following maximum flooding when the sea level begins to fall. The lower contact of the shellbed appears to be an erosional surface, the hollows of which were infilled by fauna during a period of sediment starvation. The sharp upper contact marks the point at which sedimentation resumed in response to further shallowing. Facies of the Lower Castlecliff Siltstone which overlie the Lower Castlecliff Shellbed support a falling sea-level interpretation.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990), the Lower Castlecliff Siltstone and Shellbed are assigned to the upper part of Oxygen Isotope Stage 15 (c. 500 Ka) by Abbott and Carter (1994). Pillans (1994) assigns the Lower Castlecliff Siltstone to the lower peak within Oxygen Isotope Stage 15 and correlates it with the Onepuhi Tephra in Rangitikei Valley (see **Figure 1.2** and **3.1**). Fleming (1953) did not describe the Lower Castlecliff Siltstone formation in the Castlecliff section at Wanganui. In Rangitikei Valley the formation is represented by shallower water facies (Abbott, 1994), probably due to closer proximity to the basin margin.

The Rangitikei correlative of the Lower Castlecliff Shellbed is most likely the shellbed containing *P. marwicki* which lies stratigraphically between the Toms Conglomerate and the Onepuhi Shellbeds (Te Punga 1953). Beu *et al* (1986), Pillans (1994) and Abbott (1994) correlate the Lower Castlecliff Shellbed with the lower Onepuhi Shellbed in the Rangitikei section.

Across the basin, the Lower Castlecliff Shellbed thins from 1 m at Castlecliff, to 0.3 m in Turakina Valley and the shellbed retains its undulating lower surface. The formation in Rangitikei Valley is made up of shallower water facies (Abbott, 1994), which is consistent with its position nearer to the basin margin (see **Figure 3.1**).

Table 2.2.7 : Palaeontology of the Lower Castlecliff Shellbed in the Turakina Valley

FAUNA	f 85	f 89
Bivalvia		
Atrina zelandica		p
Barbatia novaezelandiae	p	
Cardita aoteana	f	
Caryocorbula zelandica	c	p
Chlamys gemmulata	c	
Chlamys zelandiae	p	
Dosinia (Kereia) greyi	p	
Dosinia zelandica	p	
Elliptolellina urinatonia	p	
Felaniella (Zemysia) zelandica	s	
Gari hodgei	f	
Gari stangeri		p
Glycymeris modesta	s	
Hiatella aretica	p	
Limaria orientalis	p	
Mesopeplum convexum	f	
Myadora boltoni	f	p
Myadora novaezelandiae	f	
Myadora striata	a	p
Nemocardium (Pratulum) pulchelllum	p	p
Notocallista multyistriata	s	p
Nucula nitidula	f	
Panopea wanganuica/smithae		p
Pecten benedictus marwicki	s	
Pleuromeris marshalli	f	
Pleuromeris zealandica	c	s
Purpurocardia purpurata	c	
Scalpomactra scalpellum	c	
Talochlamys gemmulata		p
Tawera spissa	a	c
Tiostrea chilensis lutaria	c	p
Tucetona laticostata	p	
Gastropoda		
Agatha georgina	p	
Amalda sp.	s	
Amalda (Gracilispira) novaezelandiae		p
Amalda mucronata	p	
Antimelatoma buchanani	p	
Antisolarium egenum	c	p
Ataxocerithium sp.	p	
Austrofusus glans		p
Buccinulum linea	p	

Table 2.2.7 cont'd

FAUNA - GASTROPODA CONT'D.	f85	f89
Calliostoma sp.	p	
Crepidula costata	p	
Dolicrossea vesca	p	
Emarginula striatula	p	
Leucatona ambigua	f	p
Liratilia conquisita	p	
Maoricolpus roseus	c	p
Michrelenchus sp.	c	
Neoguraleus sp.	s	f
Nozeba emarginata	p	
Phenatoma rosea	p	
Pisinna sp.	p	
Retusa oruaensis	p	
Seila sp.	p	
Sigapatella novaezelandiae	s	
Stiracolpus cf. blacki	p	
Stiracolpus aff. symmetricus		s
Stiracolpus ? waikopiroensis		p
Struthiolaria papulosa		p
Tanea zelandica	p	
Tomopleura subalbula	s	
Trochus (Coelotrochus) tiaratus	f	p
Trochus (Thorista) viridis	p	
Xymene bonnetti		p
Xymene plebeius	c	s
Xymene pusillus	s	
Xymene traversi	f	
Zeacolpus vittatus	f	
Zegalerus tenuis	c	s
Scaphopoda		
Antalis nana	f	p
Bryozoa (Button & Stick-shaped)	s	p
Brachiopoda		
Waltonia inconspicua	f	p
Echinoidea		
Fellaster zelandiae	p	

[Fauna identified by Alan Beu]

p = present f = few s = several c = common a = abundant

Plate 2.2.32 Lower Castlecliff Shellbed at S23/086294 on a farm track c. 0.4 km down valley from the end of Howie Road. The shellbed consists of muddy, silty sand with abundant, diverse fauna (Facies TCS-2). The lower contact is undulating to dm-scale and represents an erosional surface. The top of the spade handle marks the top surface of the shellbed and which represents the point at which sediment was again introduced into the environment of deposition in response to a falling sea-level. The bedded siltstone unit above the shellbed is part of the Lower Castlecliff Siltstone.

Plate 2.2.33 Lower Castlecliff Shellbed at S23/082296 in a small valley just down valley from the site in Plate 2.2.32. At this location, intense burrowing is evident below the shellbed (dominant species is *Maoricolpus*) into a massive siltstone unit of the Lower Castlecliff Siltstone. The lower contact of the shellbed (just above the spade handle) is undulating to dm-scale.

Plate 2.2.32

Shellbed

Shellbed

Burrowing zone

Plate 2.2.33

Plate 2.2.34 Lower Castlecliff Siltstone at S23/086294 on a farm track, c. 0.4 km down valley from the end of Howie Road. The siltstone is lenticular-bedded and streaky laminated (Facies BZ-2).

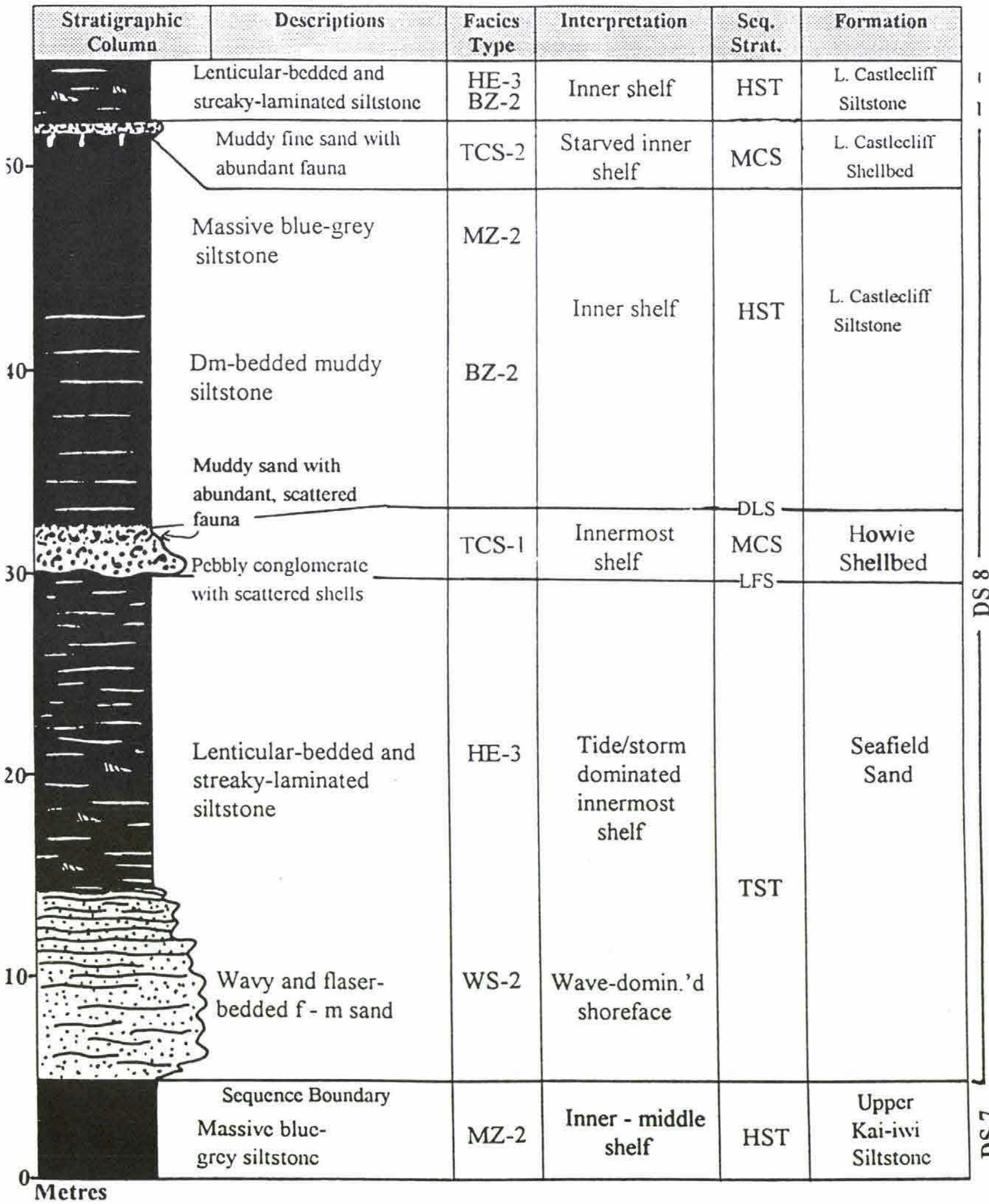


Figure 2.2.10 Stratigraphic summary diagram for Depositional Sequence 8 in Turakina Valley from site S23/086294 - 073302 down valley from the end of Howie Road (See map and cross-section at the back of this thesis).

2.2.10 Depositional Sequence 9

Pinnacle Sand

Type Section : Castlecliff section, 4 km south-east of Omapu Stream.

Name : named after a landform at Castlecliff known as the 'Pinnacles' (Fleming, 1953).

Thickness : 7 - 10 m in Turakina Valley. Incompleteness of exposure in Turakina Valley has made it difficult to determine the thickness of the Pinnacle Sand. However, the entire unit (22 m) is exposed in a bluff on the Whangaehu side of the Turakina River (S22/036311) but this location is inaccessible (Woolfe, 1987).

Reference Section : S23/056301 Farm track leading to gravel quarry north of Waimutu Road.

Descriptive Sections : S23/057295 Farm track following stream up valley closest to Waimutu Road

S22/069316 Steep hillside off Morgans Road (south side), 0.5 km down valley from farm house at the end of Morgans Road.

Descriptions

The Pinnacle Sand at the reference section unconformably overlies a bedded siltstone unit (Lower Castlecliff Siltstone). Here the formation consists of up to 10 m of unbedded, loose, brown, medium, well-sorted **(sample S51, Appendix B)** sand (Facies WS-2). The upper and lower contacts were not exposed. This section is summarised in **Figure 2.2.11**.

At DS (S23/057295) on a farm track near the stream closest to Waimutu Road, only a small section of the Pinnacle Sand is exposed directly below the Tainui Shellbed. Here the contact between the two formations is an abrupt transition from finely parallel-laminated, loose, brown sand to muddy shellbed. The outcrop at DS (S22/069316), a cliff face south of Morgans Road, also displays only the upper 1 m of the Pinnacle Sand. Here the formation is a finely parallel-laminated, well-sorted **(sample S27, Appendix B)** fine sand with some fine flaser bedding (Facies WS-2). The contact between the Pinnacle Sand and the Tainui Shellbed is very sharp, with wavy, cm-scale relief and some burrowing is evident at the contact **[Plate 2.2.35]**.

The overall distribution of Depositional Sequence 9 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

Palaeontology

Macrofauna not observed

Interpretation

The Pinnacle Sand comprises the TST of Sequence 9 in the Wanganui Basin sequence.

The well - sorted and parallel-laminated nature of the sands of the Pinnacle Sand indicates deposition in a shallow shoreface environment where waves affect sedimentation (section 2.1.4a). The lower contact was nowhere exposed in Turakina Valley. The sharp upper contact represents the unconformity of the Local Flooding Surface for Depositional Sequence 9 in Turakina Valley.

The sediments of the formation represent a shallowing trend eastward across the basin where the facies of the formation at Castlecliff indicate deposition on the inner shelf, whereas from Whangaehu Valley (Woolfe, 1987) to Rangitikei Valley (Potter, 1984), the facies indicate an intertidal shoreface environment of deposition.

Age and Correlation

Abbott and Carter (1994) assigned the Pinnacle Sand to Oxygen Isotope Stage 13 (c. 480 Ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Pillans (1994) places the Pinnacle Sand within the upper part of Oxygen Isotope Stage 15 (see **Figure 1.2**).

The thickness of the Pinnacle Sand increases from 10 m at Castlecliff (Abbott and Carter, 1994) to 22 m in Turakina Valley (Woolfe, 1987). The Rangitikei equivalent may be the sand members between the Onepuhi shellbeds (Potter, 1984). Beu *et al* (1986) correlate the formation to the interval between the Otapatu and Onepuhi Shellbeds. Pillans (1994) correlates the Pinnacle Sand to the Onepuhi Shellbeds in Rangitikei Valley (see **Figure 3.1**).

Plate 2.2.35 Pinnacle Sand/Tainui Shellbed contact at S22/069316 along the top part of a steep hillside just south of Morgans Road and c. 500 m west of the farmhouse at the upper end of the road. The Pinnacle Sand has faint parallel laminations and fine mud flasers within a fine sand (Facies WS-2). The contact with the Tainui Shellbed is sharp and burrowed. This lower contact marks the Local Flooding Surface for Depositional Sequence 9 (see dashed black line). The Tainui Shellbed is made up of two distinct parts; a lower muddy, fine sand with abundant smaller fauna and an upper muddy sand with abundant larger fauna which is more shell - supported (Facies TCS-3, Type B Shellbed). The shellbed is about 1.5 m thick at this location (40 cm knife for scale).

Tainui Shellbed

Type Section : Castlecliff section, 4.2 km south-east of Omapu Stream.

Name : name by Fleming (1953) given to a shellbed in the Wanganui Coast section which contains *Pecten tainui*.

Thickness : 1-1.5 m in Turakina Valley.

Reference Section : S23/057295 Farm track c.2 km NE of the lower end of Waimutu Road.

Descriptive Sections : S22/059319 Paddock off Turakina Valley Road just south of Morgans Road.
S22/069316 Steep hillside off Morgans Road (south side), 0.5 km west of the farm house at the end of Morgans Road.

Descriptions

In Turakina Valley, the Tainui Shellbed is generally a bluff-forming, fine, muddy, yellow-brown sand with abundant, diverse fauna. Where the shellbed is well indurated, large blocks have broken loose and tumbled down slopes to the valley floor e.g. DS (S22/059319).

At the reference section, the shellbed overlies a loose, parallel-laminated, fine, brown sand which comprises the Pinnacle Sand. The contact from sand to shellbed is sharp and is overlain by 1m of muddy sand containing abundant small fauna. Crude stratification of shells along possible bedding planes occurs in the lower regions of the shellbed **[Plate 2.2.36]**. Above this is 1 m of muddy sand with abundant, closely packed larger fauna (Facies TCS-3, section 2.1.4c). It was difficult to determine, from lithology, whether the upper and lower parts of the unit represent two separate shellbeds. The only notable differences are the size of the fauna and some minor differences in faunal assemblages **[Table 2.2.8]**. Because of the obvious lithologic change from sand (Pinnacle Sand) to shellbed, the unit has been classed as one shellbed and named the Tainui Shellbed. The shellbed grades rapidly over a few cm into the massive, muddy Shakespeare Cliff Siltstone, of which approximately 2 m is exposed at the reference section **[see Plate 2.2.37]**. This section is summarised in **Figure 2.2.11**.

At DS (S22/069316) on a hillside just south of Morgans Road, the Tainui Shellbed again consists of c.1-1.5 m of muddy sand with abundant, diverse fauna and a concentration of the larger shells in the upper 0.4-0.6 m of the shellbed (Facies TCS-3, section 2.1.4c). The contact with the underlying parallel-laminated Pinnacle Sand is very sharp and has slight, cm-scale relief. Small burrows are evident at the contact **[see Plate 2.2.35]**. The Tainui Shellbed grades over 10 - 20 mm into the Shakespeare Cliff Siltstone.

The overall distribution of Depositional Sequence 9 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection Sites: S23/057295 (S23/ f 84a (upper) and b (lower))
S22/069316 (S22/ f 146)

On one field excursion to the reference section, a specimen of *Pecten tainui toi* was excavated from the lower part of the Tainui Shellbed. Many specimens of *Pecten tainui tainui* were found in the upper 0.6 m of the shellbed where other larger shells such as *Atrina* and *Tucetona* also occur. Although not conclusive, it is believed that several specimens of *Pecten tainui toi* were also found in the uppermost part of the shellbed. A new *Pecten* subspecies was also discovered at this location. It strongly resembles *P. jacobaeus* from the Mediterranean region and it has been suggested to name this new *Pecten* subspecies *P. jacobaeus tainui* (Beu pers. comm., 1995) **[Plate 2.2.37]**. Woolfe (1987) also recorded a diverse *Pecten* assemblage from the Tainui Shellbed in Whangaehu Valley. At the Castlecliff section, *P. tainui toi* occurs only in the top 1 m of the Pinnacle Sand (Beu pers. comm., 1995). In Turakina Valley, the evidence to support a Toi zone in the same stratigraphic position is inconclusive. The shellbed can therefore be placed within the Tainui Zone (Fleming, 1957) (Figure 2.1.5 and 2.1.6). Species such as *Purpurocardia*, *Tawera* and *Chlamys* also commonly occur within the shellbed **(Table 2.2.8, Appendix E)**.

Interpretation

The Tainui Shellbed comprises the MCS for Depositional Sequence 9 in the Wanganui Basin Pleistocene sequence.

The Tainui Shellbed was deposited unconformably upon the Pinnacle Sand where the contact represents the Local Flooding Surface. The shellbed is indicative of a period of sediment starvation on the inner shelf due to sudden deepening conditions as the depocentre moves landward (section 2.1.4c). The graded upper contact with the Shakespeare Cliff Siltstone, represents the Downlap Surface for Sequence 9 in Turakina Valley.

The presence of articulated *Neothyris sp.* suggests deposition in shallow water (c. 10 m), in a subtidal, current swept, open coast environment. Sandy beach taxa such as *Dosinia, Spisula, Paphies, Oxyperas*, and estuarine *Austrovenus* **(Table 2.2.8)** were most likely transported into the deposition site (Beu pers. comm., 1995).

The occurrence of crude stratification within the lower part of the shellbed at the type section indicates some periodic wave action may have affected sedimentation.

Age and Correlation

Based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990), Abbott and Carter (1994) placed the Tainui Shellbed within Oxygen Isotope Stage 13 (c. 480

Ka). Pillans (1994) placed the Tainui Shellbed within the upper part of Oxygen Isotope Stage 15 (see **Figure 1.2**).

Across the basin, the formation decreases in thickness from 4 m at Castlecliff to 1.5 m in Turakina Valley and a slight difference in facies and faunal assemblage was noted.

Fleming (1953) and Pillans (1994) correlated the Tainui Shellbed with the Onepuhi Shellbeds in Rangitikei Valley (see **Figure 3.1**). The shellbed was also correlated with the Otapatu Shellbed (Rangitikei Valley) of Potter (1984). Facies of the shellbed in Rangitikei Valley represent deposition in shallower water than in Turakina Valley and Castlecliff.

Table 2.2.8 : Palaeontolgy of the Tainui Shellbed in Turakina Valley

FAUNA	f 84a	f 84b	f 146
Bivalvia			
Atrina sp.	p		p
Austrovenus crassitesta			p
Austrovenus stutchburyi			f
Barbatia novaezelandiae	p		
Caryocorbula zelandica	f	f	
Chlamys gemmulata	s	p	p
Dosinia (Phacosoma) maoriana	p		p
Dosinia ? subrosea	p	s	
Felaniella (Zemysia) zelandica	p	f	
Glycymeris modesta	c	c	p
Leptomya retiaria	p		
Limatula maoria	p		
Mesophylum convexum	p		
Modiolus arealatus			p
Nucula nitidula	f	f	
Oxyperas elongata			p
Paphies donacina			p
Pecten jacobaeus tainui	p		
Pecten tainui tainui	p		p
Pecten tainui toi	p	p	p
Pleuromeris zealandica	s	f	
Purpurocardia purpurata	c	p	c
Scalpomactra scalpellum	s	s	
Spisula aequilatera			p
Tawera spissa	c	c	c
Tiostrea charlottae			s
Tiostrea chilensis lutaria	c	f	s
Tucetona laticostata	p	p	c
Gastropoda			
Alcithoe arabica	p		
Amalda (Baryspira) mucronata	p	p	p
Amalda (gracilispira) novaezelandiae	p	p	
Antimelatoma buchanani	p	p	
Antisolarium egenum		f	
Aoteadrilla wanganuiensis	p		
Astrea heliotropium	p		
Austrofusus glans	p	p	
Austromitra planata	p		
Bucinulum linea	s		
Cominella elegantula	p		
Duplicaria tristis	f	f	
Glaphryrina caudata	p		

Table 2.2.8 cont'd

FAUNA - GASTROPODA CONT'D	f84a	f84b	f146
Maoricolpus roseus	s		p
Michrelenchus sp.	p	s	
Microvoluta marginata		s	
Penion cuvierianus	p		
Sigapatella novaezelandiae	f	s	
Stiracolpus sp.	p		
Stiracolpus blacki		s	
Struthiolaria papulosa			p
Tugali pliocenica	p		
Xymene ambiguus		p	
Xymene Plebeius			p
Xymene pusillus		f	
Xymene traversi	p		
Zeacolpus vittatus	p		p
Zegalerus tenuis		s	
Zemitrella sulcata	s		
zethalia zelandica		f	
Brachiopoda			
Neothyris sp.	p		p
Waltonia inconspicua	s		
Scaphopoda			
Antalis nana		p	
Coelenterata, Scleractinia			
Flabellum rubrum			p
Bryozoans	s	p	

[Fauna identified by Alan Beu]

p = present
f = few
s = several
c = common
a = abundant

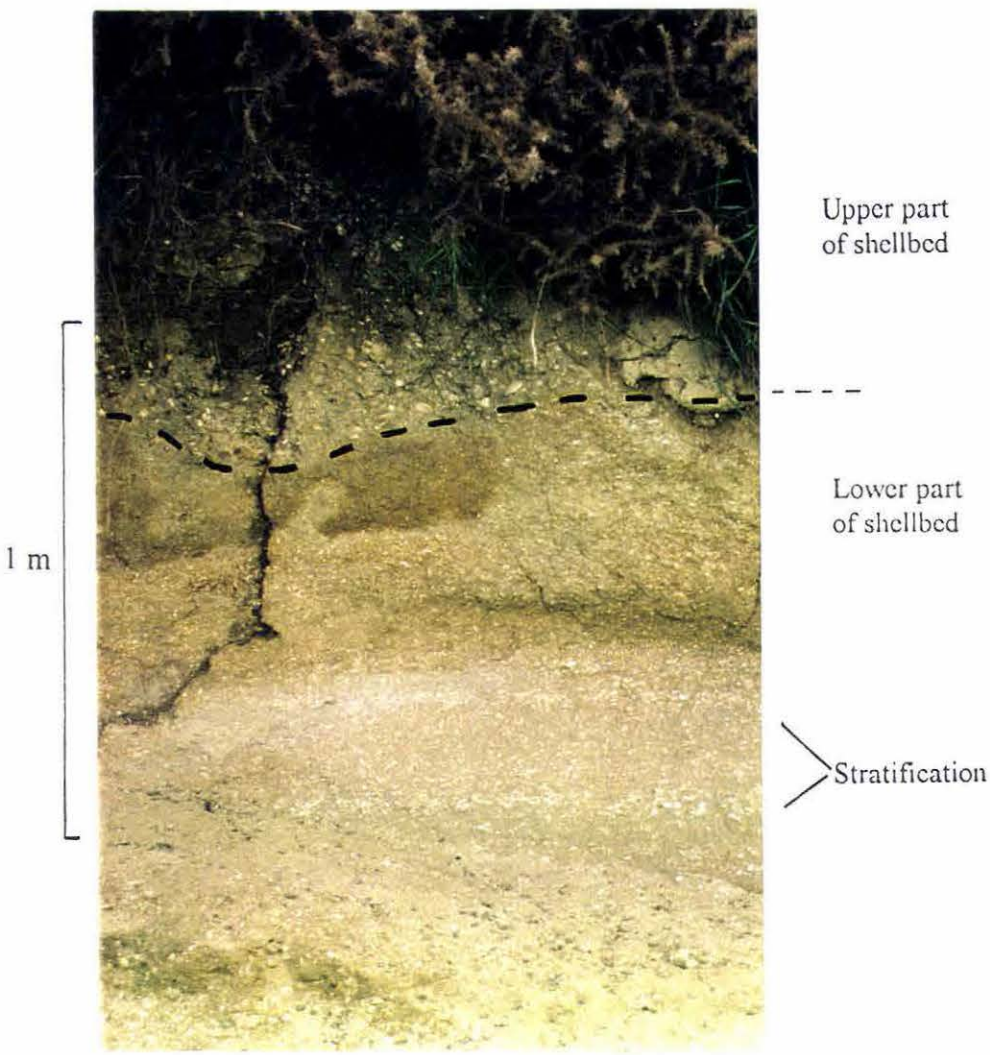
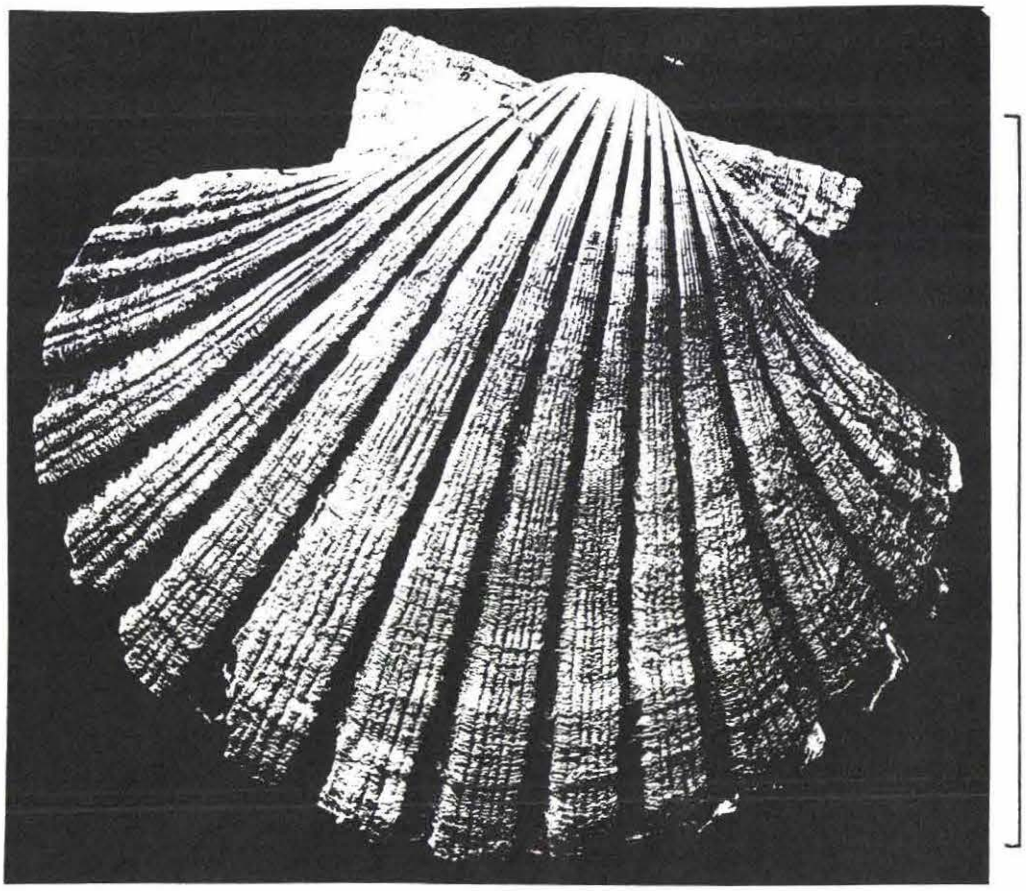


Plate 2.2.36 Tainui Shellbed at S23/057295 on a farm track c. 2 km up valley from the lower end of Waimutu Road and following the Waimutu Stream. The Tainui Shellbed consists of fine muddy sand with abundant, diverse fauna (Facies TCS-3, Type B Shellbed). The lower part of the shellbed is largely made up of small fauna with some faint stratification occurring. The upper part of the shellbed consists of mainly larger fauna just visible near the top of the photo. The shellbed is approximately 1.5 m thick.



≈13 cm
real size

Plate 2.2.37 *Pecten jacobaeus tainui* from the Tainui Shellbed at S23/057295 on a farm track c. 2 km up valley from the lower end of Waimutu Road and following Waimutu Stream. This *Pecten* subspecies closely resembles a subspecies of *Pecten* from the Mediterranean (Beu pers. comm., 1995).

Photo taken by **Wendy St George** (Institute of Geological and Nuclear Sciences, Lower Hutt).

Shakespeare Cliff Siltstone

Type Section : Castlecliff section, 5.5 km south-east of Omapu Stream.

Name : revised by Fleming (1953) from older New Zealand geological literature (see Fleming 1953, pg. 231) where the formation was referred to as the 'lower clay stratum at Shakespeare Cliff ', or 'Shakespeare Cliff Blue Clay' by earlier writers.

Thickness : 20 m exposed in Turakina Valley. The exact thickness is unknown due to poor exposure, although Woolfe (1987) recorded a thickness of 20 m for the entire formation on the Whangaehu/Turakina Interfluve.

Reference Section :	S23/048287	Farm track 1.5 km S of the lower end of Waimutu Road
Descriptive Sections :	S23/057295	Farm track NE of Waimutu Road: c. 1.5 km S of Turakina Valley Road.
	S23/032300	Farm on river side of Turakina Valley Road, (c. 1 km W of Bruce Road).

Descriptions

The Shakespeare Cliff Siltstone at the reference section consists of c. 20 m of massive, barren, blue-grey siltstone (Facies MZ-2). Bioturbation is evident lower in the outcrop. The lower contact is not exposed, and the upper contact is sharp with dm-scale relief. At DS (S23/057295), on a farm track near Waimutu Stream, only 1.5-2 m of the formation is exposed above the Tainui Shellbed. The lower contact displays an abrupt gradation from a shell - dense, muddy, silty sand to the massive, barren blue-grey siltstone **[Plate 2.2.38]**.

The cliff exposure at DS (S22/032300) next to Turakina River, c. 1 km west of Bruce Road, shows the uppermost 7-8 m of the formation. Here the unit is also a massive, barren, blue-grey siltstone (Facies MZ-2). The upper contact with the basal conglomerate member of the Shakespeare Cliff Sand is sharp with dm-scale relief. This section is summarised in **Figure 2.2.11**.

The overall distribution of Depositional Sequence 9 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Macrofauna not evident

Interpretation

The Shakespeare Cliff Siltstone comprises the HST of Depositional Sequence 9 in the Turakina Valley.

Facies indicate deposition on the inner - middle shelf (section 2.1.4d). The abrupt gradation displayed in the lower contact with the Tainui Shellbed, marks the Downlap Surface for Depositional Sequence 9. The very sharp, erosive upper contact marks the sequence boundary between Depositional Sequences 9 and 10.

Age and Correlation

Abbott and Carter (1994) placed the Shakespeare Cliff Siltstone within the upper part of Oxygen Isotope Stage 13 (c. 450 Ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Pillans (1994) places the Shakespeare Cliff Siltstone in the upper part of Oxygen Isotope Stage 15 (560 Ka) (see **Figure 1.2**).

The formation thickens across the basin from c. 10 m at Castlecliff (Fleming, 1953) to 20 m in Turakina Valley and the nature of the formation does not appear to change to any large extent across the basin. The occurrence of scattered macrofauna recorded at most sites from the coast to Whangaehu (Fleming, 1953; Woolfe, 1987), was not evident in outcrop in Turakina Valley. The reverse-grading, sandier - up nature of the formation observed on the Whangaehu/Turakina Interfluve (Woolfe, 1987) was not evident in Turakina Valley. The unit in Turakina Valley more closely resembles the formation at the Castlecliff section and therefore, the sandy nature of the unit on the Interfluve may be due to a local influx of sand into the deposition site.

In Rangitikei Valley, the sandy unit between the Ruamahanga Conglomerate and Otapatu Shellbed is thought to represent the Shakespeare Cliff Siltstone (Beu *et al*, 1986; Pillans, 1994) (see **Figure 3.1**). The sandier nature of the formation in Rangitikei Valley (Potter, 1984) may indicate shallowing conditions at the basin margin, or it may be a local feature related to sediment source and/or supply.

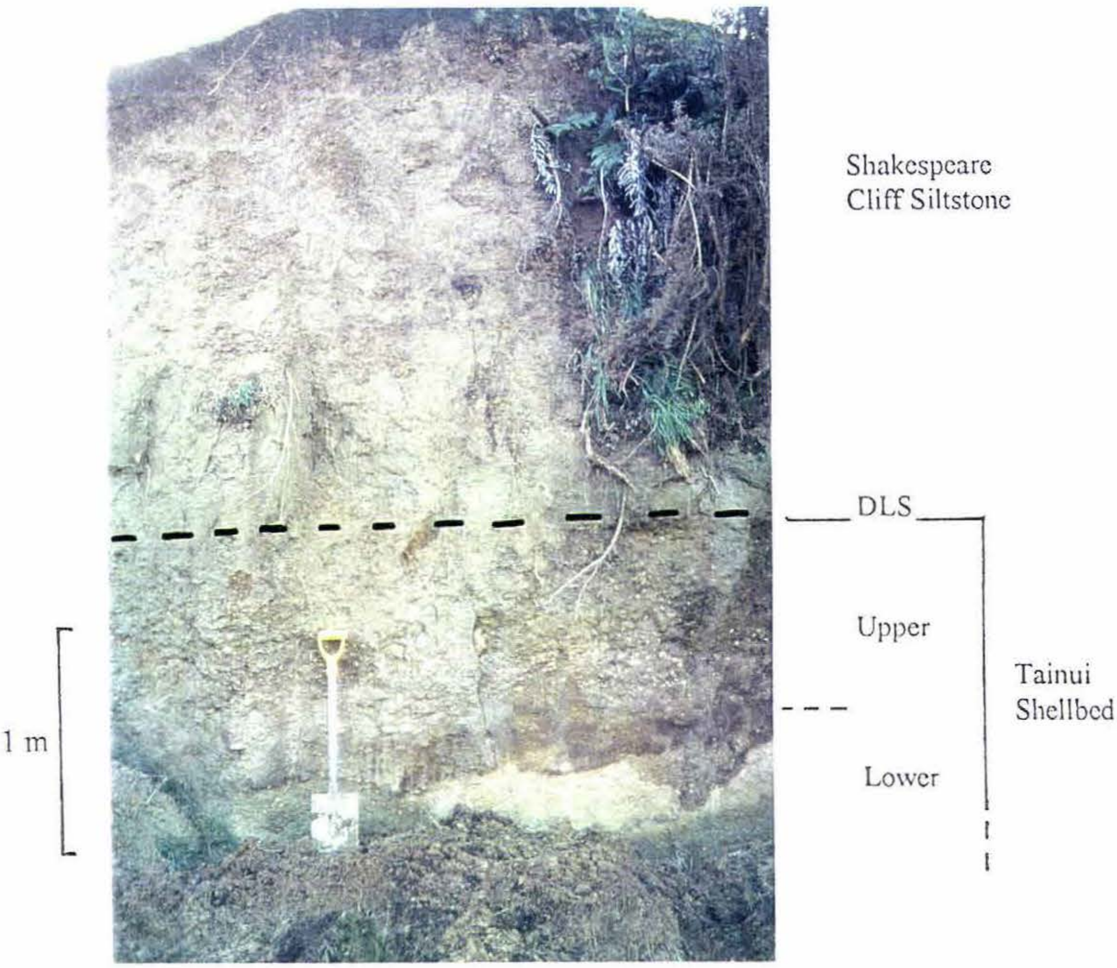


Plate 2.2.38 Tainui Shellbed/Shakespeare Cliff Siltstone contact at S23/057295 on a farm track c. 2 km up valley from the lower end of Waimutu Road and following the Waimutu Stream. The contact between the two formations is quite sharp and marks the Downlap Surface for Depositional Sequence 9. The Shakespeare Cliff Siltstone is made up of massive blue-grey siltstone (Facies MZ-2) of which up to 2 m is exposed at this location.

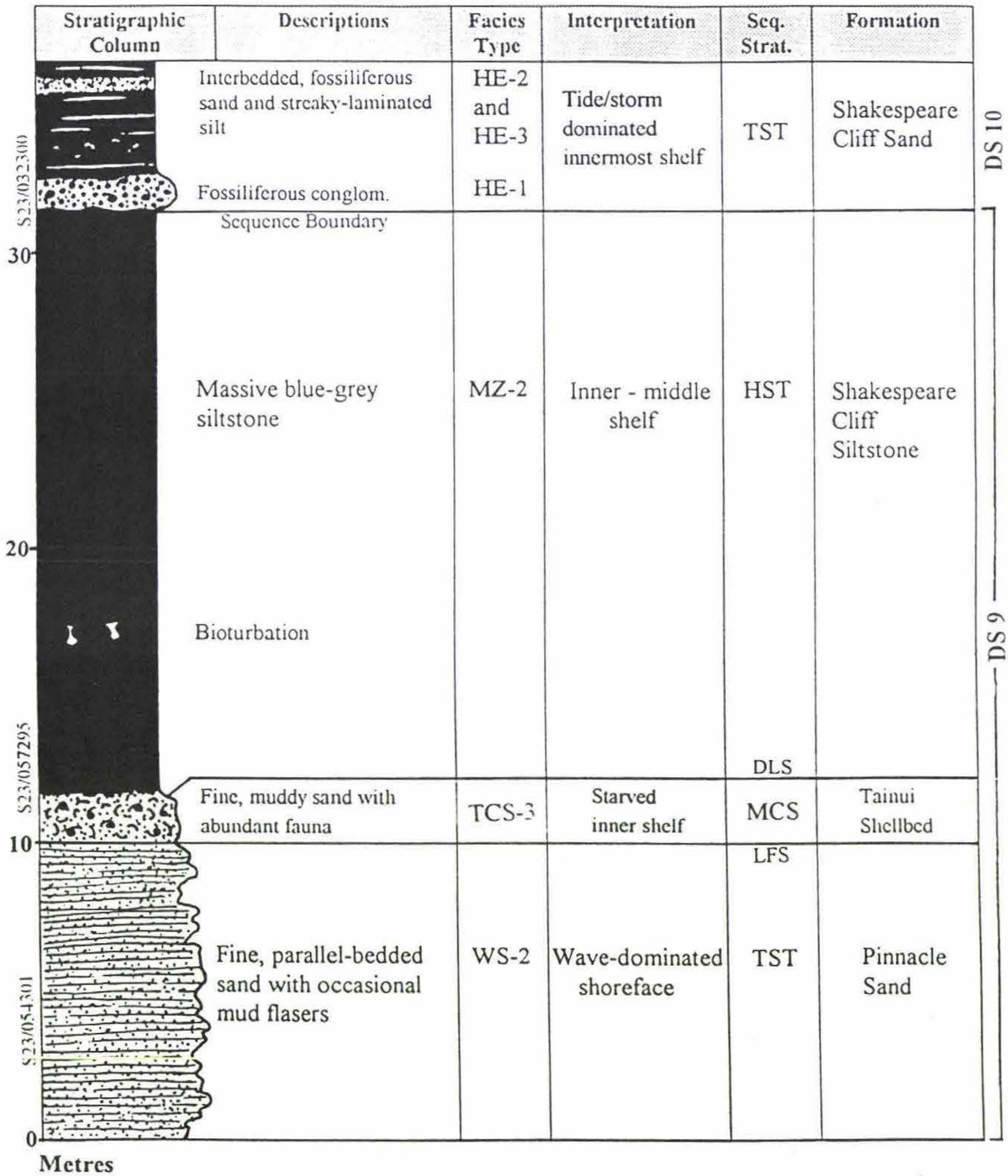


Figure 2.2.11 Stratigraphic summary diagram for Depositional Sequence 9 in Turakina Valley from sites S23/054301, S23/057295 north of Waimutu Road and site S23/032300, west of Bruce Road (See map and cross-section at the back of this thesis).

2.2.11 Depositional Sequence 10

Shakespeare Cliff Sand

Type Section : Castlecliff section, 6 km south-east of Omapu Stream.

Name : proposed by Fleming (1953) for the 'CU 5 *Zethalia - Amphidesma* Sands' in the coastal section at Castlecliff (Fleming, 1947a).

Thickness : Basal 5 m exposed in Turakina Valley. Woolfe (1987) reported a thickness of c. 40 m from a well exposed outcrop on the Turakina side of the Whangaehu/Turakina Interfluve at grid reference S22/032301.

Reference Section : S23/031298 Cliff face on Whangaehu side of Turakina River west of Bruce Road and Waimutu Road.

Descriptive Sections : S22/031309 Small western tributary of the Turakina River west of Waimutu Road.

S23/048287 Farm track 1 km south west of the lower end of Waimutu Road.

Descriptions

The outcrop of Shakespeare Cliff Sand at the reference section has a basal, closely - packed, fossiliferous conglomerate (Facies HE-1) c. 1 m thick. Greywacke clasts are up to 3 cm in diameter and tend to be disc shaped. The lower contact overlying the Shakespeare Cliff Siltstone is sharp and erosive with dm-scale relief. Approximately 4 m of interbedded faintly streaky-laminated silt and sand (Facies HE-2 and 3) overlies the conglomerate **[Plate 2.2.39]**. Almost directly above the conglomerate a fossiliferous unit within the siltstone occurs. The fauna are dense near the conglomerate and become increasingly sparse up - section. The fossiliferous bedded siltstone becomes barren 1 m above the conglomerate and is up to 2 m thick. This siltstone member passes rapidly into 0.1-0.2 m of loose, grey, medium sand with scattered fauna which appears to be laterally discontinuous. Approximately 1 m of the bedded siltstone is again visible above the sandy lens at which point, the stratigraphy becomes obscured. The entire outcrop is approximately 4 m thick and is summarised in **Figure 2.2.12**.

At DS (S22/031309) in a western tributary of the Turakina River west of Waimutu Road, 3 m of the Shakespeare Cliff Sand is exposed. It was not possible to determine where this outcrop could be placed within the overall formation, although, lithologically it does resemble the exposure at the reference section. A 0.3 m basal, closely - packed, fossiliferous conglomerate (Facies HE-1) also occurs at this location, although the greywacke pebbles range from 1 -2 cm in diameter. The lower contact is obscured and the full extent of the conglomerate is probably not represented **[Plate 2.2.40]**. The conglomerate ends abruptly with cm - scale relief. Approximately 0.2-0.3 m of faintly laminated and bioturbated sandy silt overlies the conglomerate and grades rapidly over a few cm into a shellbed of similar lithology (Facies ZS-2, Type A2 Shellbed). The faunal assemblage differs quite markedly from that of the reference section **[sample f 161b, Table 2.2.9]**. There is a rapid transition over 20-30 mm from shell - rich, fine, sandy silt into faintly laminated barren siltstone (Facies HE-3). Approximately 1.5 - 2 m of this siltstone member is exposed at this site.

The Shakespeare Cliff Sand is again seen at DS (S23/048287) south of Waimutu Road. Here up to 4.5 m of unfossiliferous, parallel-bedded silt and fine sand **(sample S54, Appendix B)** represents the formation (Facies WS-2). The unit appears to become sandier up-section. The formation unconformably overlies the massive blue-grey silt of the Shakespeare Cliff Siltstone. This lower contact is sharp with dm - scale relief.

The overall distribution of Depositional Sequence 10 in Turakina Valley is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection sites : S23/031298 (S23/ f 86a) basal conglomerate

(S23/ f 86b) shellbed in bedded siltstone almost directly above conglomerate
(S23/ f 86c) fossiliferous sandy lens within the siltstone member

S22/031309 (S22/ f 161a) basal conglomerate
(S22/ f 161b) shellbed above conglomerate

An abraded fragment of *Pecten sp.* was taken from sample f 86c [**Table 2.2.9**]. Fleming (1953) placed the Shakespeare Cliff Sand within the Upper Marwicki Zone (Figure 2.1.5 and 2.1.6).

Interpretation

The Shakespeare Cliff Sand represents the TST of Depositional Sequence 10 in the Wanganui Basin Pleistocene sequence.

Lithology and faunal assemblages indicate deposition in shallow (5-10 m), high - moderately high energy, water (Beu pers. comm., 1995). The faunal assemblages of f 86a, b, and c, also represent deposition in the similar environment, although sedimentation concentrated larger species into the basal conglomerate. In general then, the facies at the reference section and DS (S22/031309) represent deposition within the transition zone on the shelf between the shoreface and innermost shelf environments (section 2.1.4a and b). Facies at DS (S23/048287) indicate deposition on a wave dominated shoreface (section 2.1.4a). The sharp lower contact represents the lower sequence boundary for Depositional Sequence 10 in Turakina Valley.

Age and Correlation

Abbott and Carter (1994) assign the Shakespeare Cliff Sand to the lower part of Oxygen Isotope Stage 11 (c. 410 Ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Pillans (1994) places the formation within Oxygen Isotope Stage 13 (510 Ka) (see **Figure 1.2**).

The formation thickens across the basin from 12 m at Castlecliff (Fleming, 1953) to 35 - 40 m in Turakina Valley (Woolfe, 1987). A basal conglomerate was not evident at the Castlecliff section, although it was observed in Matarawa Valley, near Okoia (Fleming, 1953) and again in Whangaehu Valley (Woolfe, 1987). The Shakespeare Cliff Sand correlative in Rangitikei Valley is most likely the Ruamahanga Conglomerate (Te Punga, 1952; Pillans, 1994) (see **Figure 3.1**).

Table 2.2.9 : Palaeontology of Shakespeare Cliff Sand in Turakina Valley

FAUNA	f86a	f86b	f86c	f161a	f161b
Bivalvia					
Austrovenus stutchburyi				p	
Carycorbula zelandica		s		p	s
Cuna sp.				p	
? Cyclomactra sp.			s		
Dosinia (Phacosoma) subrosea					s
Dosinia zelandica	p				s
Gari lineolata					s
Glycymeris modesta		f		a	f
Leptomya retiaria					p
Limatula maoria					p
Maorimactra ordinaria					p
Modiolus areolatus					p
Myadora boltoni					s
Myadora striata		s			c
Nucula nitidula		s	p		c
Oxyperas elongatus					p
Panopea wanganuica smithae	p				
Paphies australis				p	
Pecten sp.			p	p	
Perna canaliculus					p
Pleuromeris marshalli		s		f	f
Pleuromeris zealandica		c		s	c
Purpurocardia purpurata		s		p	c
Scalpomactra scalpellum					c
Talochlamys gemmulata				s	p
Tawera sp.			p		
Tawera spissa	p	a		s	a
Tiostrea chilensis	p	f		s	f
Tucetona laticostata	p			p	
Zemysia zelandica		f			f
Gastropoda					
Alcithoe arabica	p				p
Amalda sp.					s
Amalda (Baryspira) sp.				p	
Amalda (Baryspira) australis			s		
Antisolarium egenum		f		f	s
Austrofusus glans				p	
Buccinulum sp.					p
Buccinulum linea			p		
Crepidula costata					f
Crepidula 'radiata'			p		
Leucitona ambigua					p

Table 2.2.9 cont'd

FAUNA - GASTRPODA CONT'D	f 86a	f 86b	f 86c	f 161a	f 161b
Liracraea odhneri					p
Michrelenchus ? sanguineus		c		c	c
Microvoluta biconica				p	
Neoguraleus sp.					s
Notoacmea helmsi					s
Peculator hedleyi				s	
Pelicaria vermis					p
Pervicacia tristis			p	p	
Pissina impressa					f
? Powelli setia sp.					s
Sigapatella novaezelandiae				p	s
Stiracolpus sp.		p		p	
Stiracolpus delli					s
Taniella planisuturalis			p		
Trochus tiaratus				p	f
Xymene sp.		c		s	c
Xymene ambiguus					p
Xymene expansus			c		
Xymene pusillus					p
Zeacolpus vittatus		p	p	s	
Zegalerus tenuis		c		p	c
Zethalia zelandica		s		f	f
Scaphopoda					
Antalis nana				p	
Brachiopoda					
Megasella ? sanguinea					p

[Fauna identified by Alan Beu]

p = present

f = few

s = several

c = common

a = abundant

Plate 2.2.39 Shakespeare Cliff Sand at S23/031298; a cliff face on the Whangaehu side of the Turakina River, west of Bruce Road and Waimutu Road. The photo shows the basal, fossiliferous greywacke conglomerate (Facies HE-1) and the overlying streaky-laminated siltstone (Facies HE-3). Spade is approximately 1m in length.

Plate 2.2.40 Shakespeare Cliff Sand at S23/031309 in a small western tributary of the Turakina River west of Waimutu Road. A basal, fossiliferous greywacke conglomerate (smaller clast size than in Plate 2.2.39) (Facies HE-1) is overlain by fine sand and a c. 1 m thick shellbed of the same lithology (Facies ZS-2, Type A2 Shellbed). The entire outcrop is approximately 2 m thick.

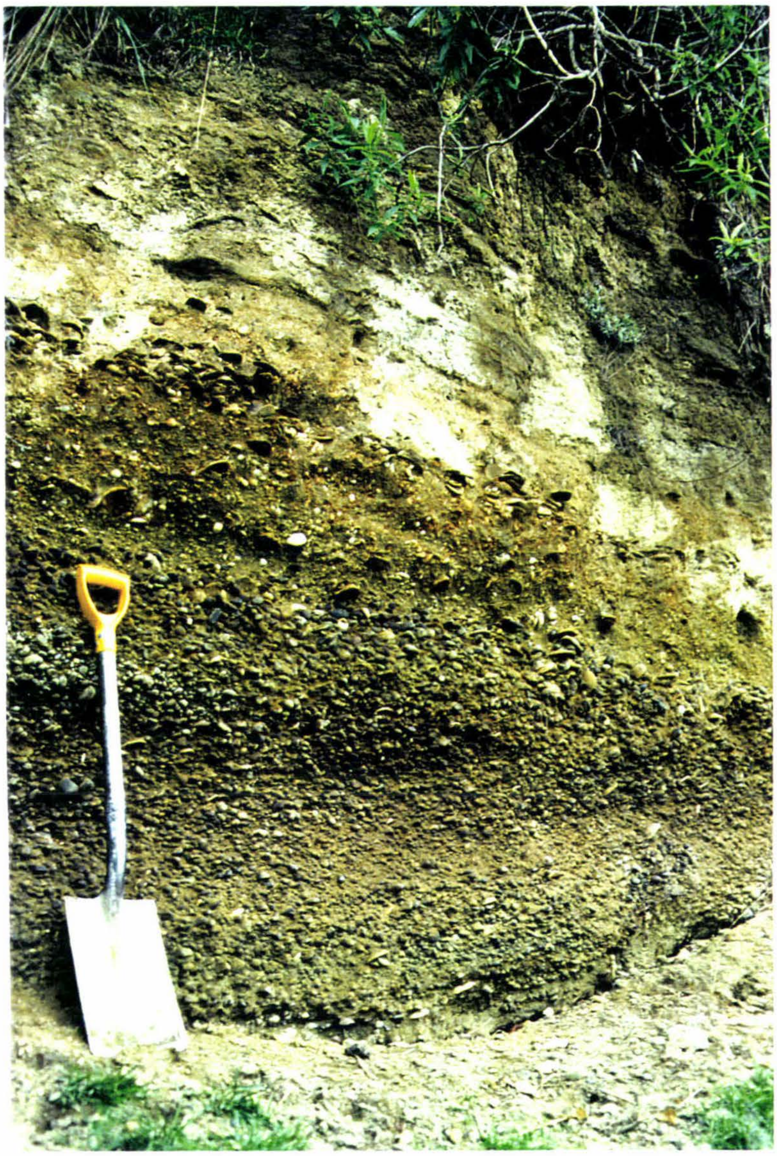


Plate 2.2.39

Plate 2.2.40

Upper Castlecliff Shellbed

Type Section : Castlecliff section, 6.5 km south-east of Omapu Stream.

Name : Proposed by Fleming (1953) for the bed CU 6 in the Castlecliff section from an earlier publication (Fleming, 1947a).

Thickness : 1.5 m in Turakina Valley.

Reference Section : S23/027294 Cliff face on the Turakina Valley Road side of the Turakina River near Bruce Road.

Descriptions

An abrupt transition from loose, grey, fossiliferous, medium, moderately well sorted sand (Facies WS-2) **(sample S17, Appendix B)**, into a shell - rich, muddy, fine sand (Facies TCS-4, section 2.1.4c), marks the contact between the Shakespeare Cliff Sand and the Upper Castlecliff Shellbed. The shellbed is approximately 1.5 m thick. The upper contact was placed where the shell - dense, muddy, fine sand grades abruptly into a massive, grey, fine sandy silt with scattered fauna, here designated as the lower part of the Karaka Siltstone **[Plate 2.2.41]**. This section is summarised in **Figure 2.2.12**.

The overall distribution of Depositional Sequence 10 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection site: S23/027294 (S23/ f 83a) **[Table 2.2.10]**

Interpretation

The Upper Castlecliff Shellbed represents the MCS of Depositional Sequence 10 in the Pleistocene, Wanganui Basin sequence.

Facies indicate deposition on a starved inner - shelf (section 2.1.4c). The presence of dominant *Tawera* and *Myadora* species, and occurrence of sandy beach taxa suggest deposition in a soft - bottom environment in a few metres of water in a large bay. The fauna display a shallower trend than Type B shellbeds at Castlecliff; except the Putiki Shellbeds and unnamed units just below (Beu pers. comm., 1995). This may have been caused by higher uplift rates at sites nearer to the axial ranges. The unconformity at the base of the shellbed represents the Local Flooding Surface for Depositional Sequence 10. Although not conclusive, the upper contact may represent the Downlap Surface.

Age and Correlation

Based on the Oxygen Isotope curve of Shackleton *et al* (1990), Abbott and Carter (1994) assigned the Upper Castlecliff Shellbed to Oxygen Isotope Stage 11 (c. 380 Ka). Pillans (1994) places the formation within Oxygen Isotope Stage 13 (500 Ka) (see **Figure 1.2**).

The thickness of the shellbed across the basin, appears to decrease from 2 m at Castlecliff (Fleming, 1953) to 1.5 m in Turakina Valley. The lithology and abundance of fauna within the shellbed seems to remain constant, although the faunal assemblages in Turakina Valley represent a somewhat shallower environment of deposition compared to the Castlecliff section (Abbott, 1994). The Rangitikei Valley correlative is most likely represented by a fossiliferous, muddy sand above the Ruamahanga Conglomerate (Te Punga, 1952). Pillans (1994) correlates the Upper Castlecliff Shellbed with the Ruamahanga Conglomerate (see **Figure 3.1**).

Table 2.2.10 : Palaeontology of the Upper Castlecliff Shellbed inTurakina Valley

FAUNA	f 83a
Bivalvia	
Austrovenus stutchburyi	p
Chlamys gemmulata	s
Chlamys zelandiae	p
Divariella huttoiona	p
Dosinia (Phacosoma) subrosea	p
Felaniella (Zemysia) zelandica	s
Gari ? hodgei	p
Limatula maoria	p
Myadora striata	a
Nucula nitidula	s
Pleuromeris marshalli	f
Pleuromeris zealandica	s
Purpurocardia purpurata	s
Ruditapes largillierti	p
Scalpomactra scalpellum	f
Tawera spissa	a
Tiostrea chilensis lutaria	c
Gastropoda	
Alcithoe (Leporemax) sp.	p
Amalda (Baryspira) mucronata	p
Antisolarium egenum	a
Austrofusus glans	p
Austromitra sp.	f
Crepidula costata	f
Duplicaria tristis	s
Maoricolpus roseus	p
Michrelenchus rufozona	s
Notoacmea sp.	s
Sigapatella novaezelandiae	s
Stiracolpus sp.	f
Tanea zelandica	p
Xymene plebeius	s
Xymene pusillus	f
Zegalerus tenuis	c
Zemitrella choava	f
Zethalia zelandica	s
Bryozoa	p

[Fauna identified by Alan Beu]

p = present s = several a = abundant
f = few c = common

Plate 2.2.41 Upper Castlecliff Shellbed and Karaka Siltstone at S23/027294 at a cliff face next to the Turakina River on the Turakina Valley Road side just west of Bruce Road. The sharp basal contact of the Upper Castlecliff Shellbed is visible approximately half way up the spade and it marks the Local Flooding Surface for Depositional Sequence 10. The Upper Castlecliff Shellbed is a muddy, fine, silty sand with abundant, diverse fauna (Facies TCS-4, Type B Shellbed). The top of the shellbed may mark the Downlap Surface for this Sequence. Approximately 2.5 m of grey silty fine sand with abundant scattered fauna (Facies MZ-1) overlies the Upper Castlecliff Shellbed. This grey, fossiliferous unit most likely comprises the basal part of the Karaka Siltstone. A rapid transition into a very fine blue-grey siltstone may also represent the Downlap Surface. The fine blue-grey siltstone is overlain by Ohakean terrace gravels.

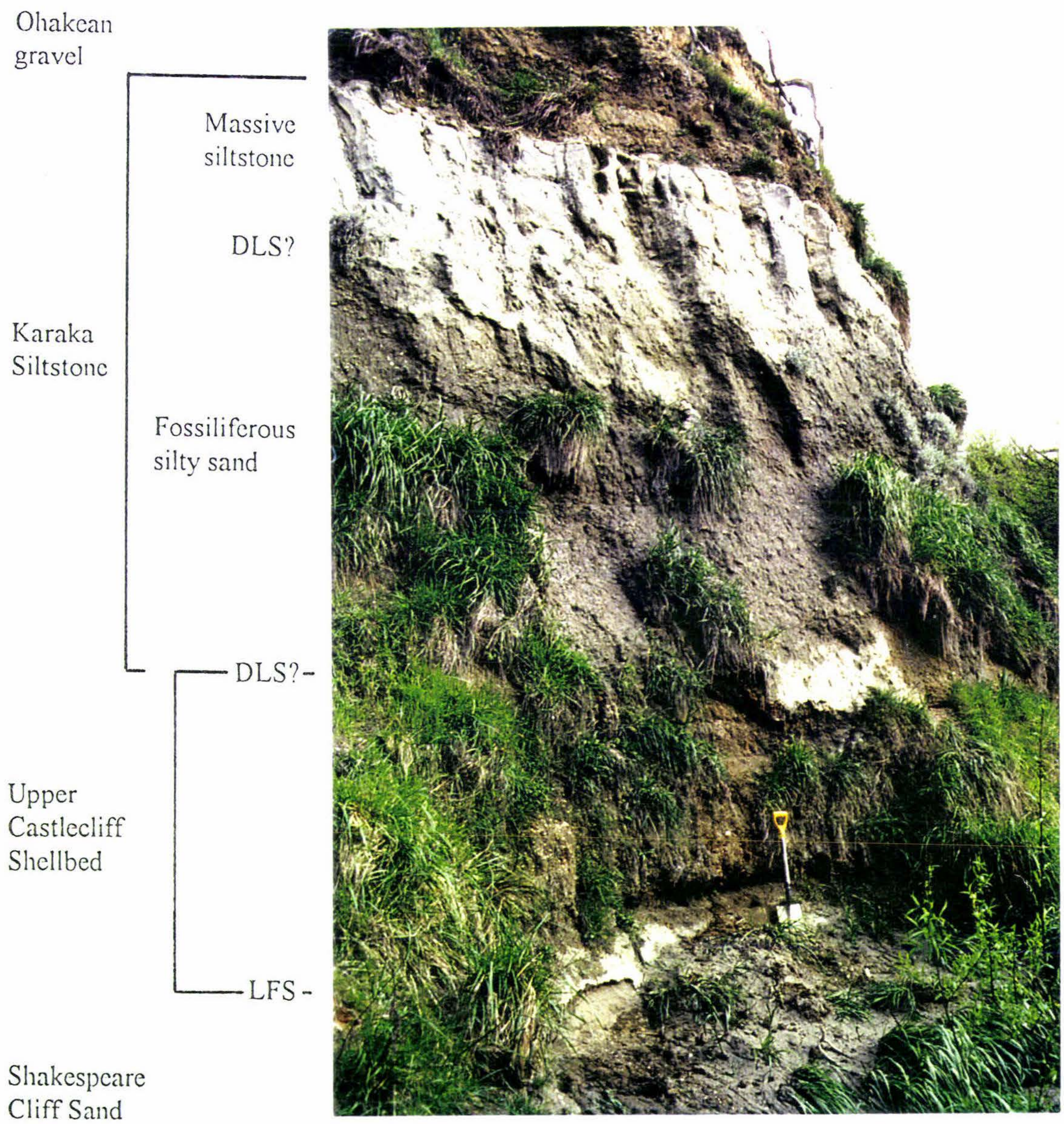

Ohakean gravel
Massive siltstone
DLS?
Karaka Siltstone
Fossiliferous silty sand
DLS?-
Upper Castlecliff Shellbed
LFS-
Shakespeare Cliff Sand

Plate 2.2.41

Karaka Siltstone

Type Section : Castlecliff section, 7 km south-east of Omapu Stream.

Name : given by Fleming (1953) for the 'CU 7 *Tawera* Silts' in the Castlecliff section (Fleming, 1947a).

Thickness : unknown for Turakina Valley (this work). Fleming (1953) reported a thickness of 12 - 17 m by the north portal of the Turakina railway tunnel.

Reference Section : S23/027294 Cliff face on Turakina Valley Road side of the Turakina River west of Bruce Road.

Descriptions

The Karaka Siltstone at the reference section for Turakina Valley, is a 1.5 - 2 m thick massive, grey, fine silty sand with abundant scattered fauna (Facies MZ-1). This fossiliferous silty sand grades rapidly over 0.1 m into a barren, massive, blue-grey siltstone (Facies MZ-2) of unknown thickness. Only 1 m of this massive, barren siltstone is exposed at this location. The Karaka Siltstone at this site is sharply overlain by an alluvial conglomerate of Ohakean age **[Plate 2.2.41]**. This section is summarised in **Figure 2.2.12**.

The overall distribution of Depositional Sequence 10 is shown on the map and cross - section at the end of this thesis.

Palaeontology

Collection site : S23/027294 (S23/ f 83b)

The highly sculptured *Pecten* subspecies found within the lower unit of the Karaka Siltstone at this site strongly resembles *Pecten marwicki* subspecies found in the

Rangitikei Valley equivalent (the Pryce Shellbed) of the Upper Castlecliff Siltstone (Beu pers. comm., 1995) **(Table 2.2.11)**. The occurrence of *P. marwicki* in the Karaka Siltstone places the formation within the Upper Marwicki Zone of Fleming (1957) (see Figure 2.1.5 and 2.1.6).

Interpretation

The Karaka Siltstone represents the HST of Depositional Sequence 10 in the Wanganui Basin sequence of Pleistocene age.

The lower contact of the Karaka Siltstone with the Upper Castlecliff Shellbed is an abrupt transition from a shell - rich unit to one containing scattered fauna, suggesting a slight hiatus marking a poorly developed Downlap Surface. Facies and faunal assemblage (particularly the presence of *Dosinia greyi*, **Table 2.2.11**), indicate a slightly more offshore environment of deposition on the inner - shelf than that of the Upper Castlecliff Shellbed (Beu pers. comm., 1995). The abundance of fauna within the lower 2 m of the Karaka Siltstone reflects the high sand content compared to the unit above. It is possible that the transition within the formation from fossiliferous to barren conditions and decrease in grain size, marks the Downlap Surface rather than the contact with the Upper Castlecliff Shellbed.

Age and Correlation

Abbott and Carter (1994) place the Karaka Siltstone within the upper part of Oxygen Isotope Stage 11 (c.370 ka) based on the Oxygen Isotope curve from ODP Site 677 (Shackleton *et al*, 1990). Pillans (1994) places the formation within Oxygen Isotope Stage 13 (c. 480 Ka) (see **Figure 1.2**).

The nature of the formation does not seem to greatly change across the basin except for a slight increase in thickness towards the east (Fleming, 1953). The occurrence of fauna at the base of the formation has previously not been recorded although fauna in other stratigraphic positions have been noted (Fleming, 1953). In the Rangitikei Valley, the Karaka Siltstone is coeval with sediments above the Kakariki Conglomerate (Potter,

1984) and represents shallower water facies than those seen between Castlecliff and Turakina Valley. Pillans (1994) correlates the Karaka Siltstone with the Pryce Shellbed (Potter, 1984) in the Rangitikei Valley sequence (see **Figure 3.1**).

Table 2.2.11 : Palaeontology of the Karaka Siltstone in Turakina Valley

FAUNA	f83b
Bivalvia	
Dosina zelandica	p
Dosinia (Kereia) greyi	p
Pecten benedictus marwicki	p
Purpurocardia purpurata	p
Gastropoda	
Alcithoe arabica	p
Amalda (Baryspira) mucronata	p
Austrofusus glans	p
Maoricolpus roseus	p
Zeacolpus vittatus	p

N.B. Selected fauna only; i.e. no indication of relative abundance of each species.

[Fauna identified by Alan Beu]

p = present

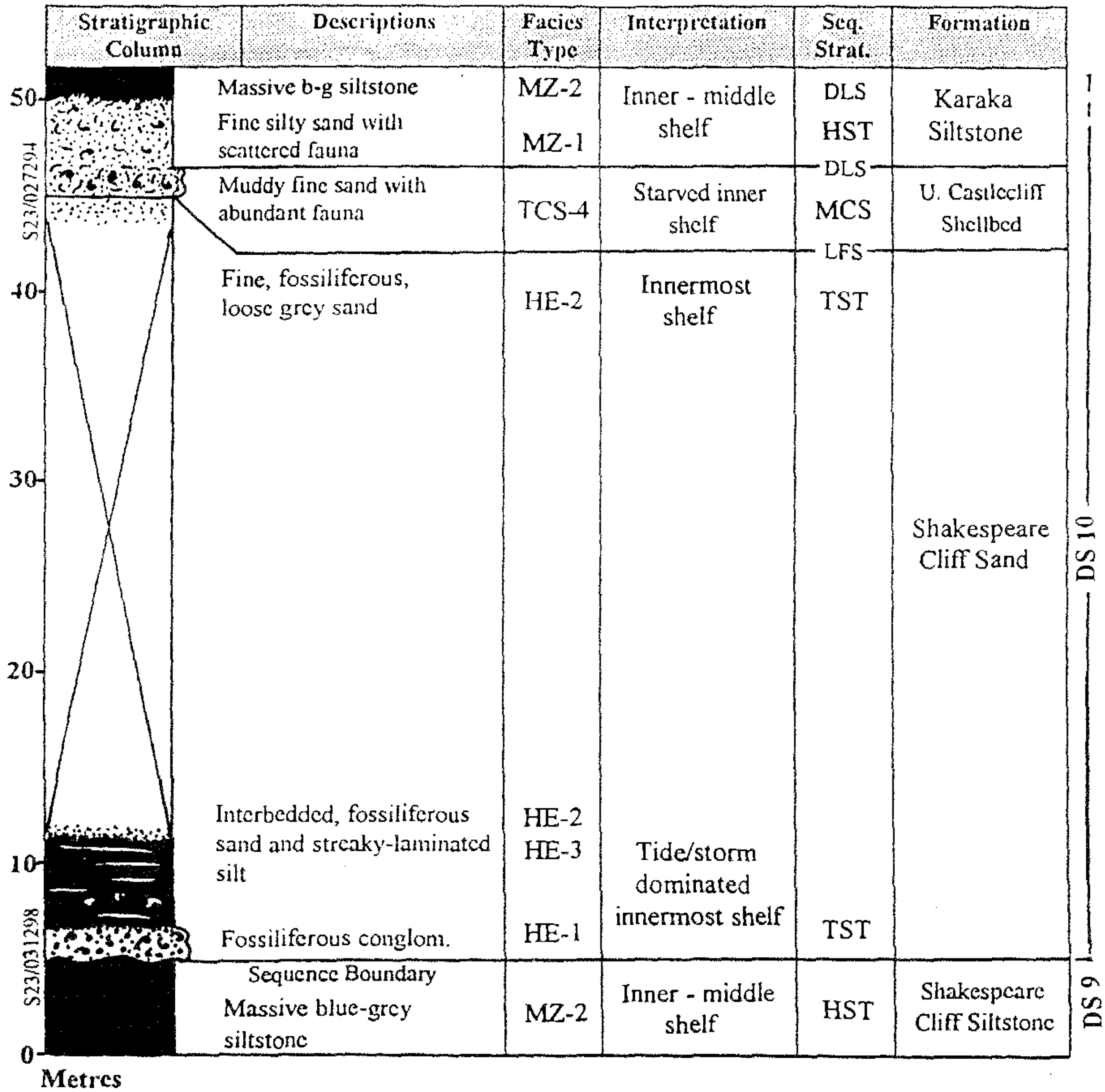


Figure 2.2.12 Stratigraphic summary diagram for Depositional Sequence 10 in Turakina Valley from site S23/031298 and S23/027294 along Turakina River west of Bruce Road (See map and cross-section at the back of this thesis).

CHAPTER THREE

DISCUSSION

Discussion

In general terms the sequence architecture and facies composition along the Castlecliff coastline is maintained eastward across the basin at least to Rangitikei Valley. Variations that occur are related to sediment supply, subsidence rate, uplift, and geomorphology of the paleoshelf. Despite these variations, it is clear that glacio - eustatic sea-level fluctuation was the dominant basin - wide control on sedimentation.

3.1 Regional Correlation

Four stratigraphic columns constructed from sites across the Wanganui Basin (Castlecliff - Whangaehu Valley - Turakina Valley - Rangitikei Valley) show the correlation of the ten depositional sequences recognised within the late Pliocene to mid-late Pleistocene time frame **(Figure 3.1)**. The section at Castlecliff is by far the best known and has recently been the focus of a study (Carter *et al* (1991), Abbott and Carter (1994), and Abbott (1994)) which applied the technique of sequence stratigraphy, in an effort to better interpret the cyclic basin fill of the Wanganui Basin. The sections at Whangaehu Valley and Rangitikei Valley are less well known and perhaps need to be reviewed. The Turakina Valley section has here been reviewed, using the facies classification developed by Abbott and Carter (1994) and Abbott (1994), with sequence stratigraphic interpretations. Several attempts have been made to correlate formations across the basin (Fleming (1953), Pillans *et al* (1994) and Abbott (1994)). A similar attempt is made here with emphasis on new information regarding the Turakina Valley section. Information used to construct representative stratigraphic columns for Castlecliff, Whangaehu Valley and Rangitikei Valley was put together from the work of Abbott and Carter (1994), Abbott (1994), Woolfe (1987), Potter (1984) and to some extent Te Punga (1953) **(Figure 3.1)**.

Several trends can be noted from the correlation diagrams:

- Depositional sequences become sandier and facies more diverse up-section;
- Formations thicken markedly towards the east of the basin;

- The first occurrence of Type B, mid-cycle shellbeds is in the early-mid Pleistocene within Depositonal Sequence 6;
- Type B, mid-cycle shellbeds thin out or disappear completely towards the east of the basin.

The first two trends can be attributed to the southward migration of the depocentre. During the late Pliocene - early Pleistocene, the depocentre encompassed an area over what is now Wanganui city to just east of Turakina Valley (see **Figure 1.4**). The deepest part of the basin therefore was lying over Whangaehu Valley at that time which is indicated by the dominance of siltstone units which are in some cases up to 5 - fold thicker than those at Castlecliff. The thickness of the siltstone units therefore, is directly related to an increased rate of subsidence as sediment load was greatest in the depocentre. Furthermore, the sections east of Castlecliff are closer to the axial ranges and were fed more directly by material originating from the Taupo Volcanic Zone and therefore sediment supply was greater in these areas, contributing to increased formation thicknesses.

During the early - mid Pleistocene the depocentre continued to move in a south-west direction in response to uplift in the north and east. The depocentre was therefore slowly forced away from its position over Whangaehu and Turakina Valley and subsidence rates decreased as sediment loading lessened away from the depocentre. In response to this, more shallow water facies were deposited as the contemporaneous shoreline moved seaward. The Rangitikei Valley section is in general dominated by more shallow water facies due to its close proximity to a major source of sediment and its position away from the depocentre during most of the Plio-Pleistocene (see **Figure 1.4**).

Mid-cycle shellbeds only appear in Depositional Sequence 6 and younger formations of Pleistocene age. Their occurrence is here believed to be in response to a change in magnitude of sea-level fluctuation where sediment - starved conditions are enhanced by a more landward position of the depocentre. This is seen in the change from 6th Order

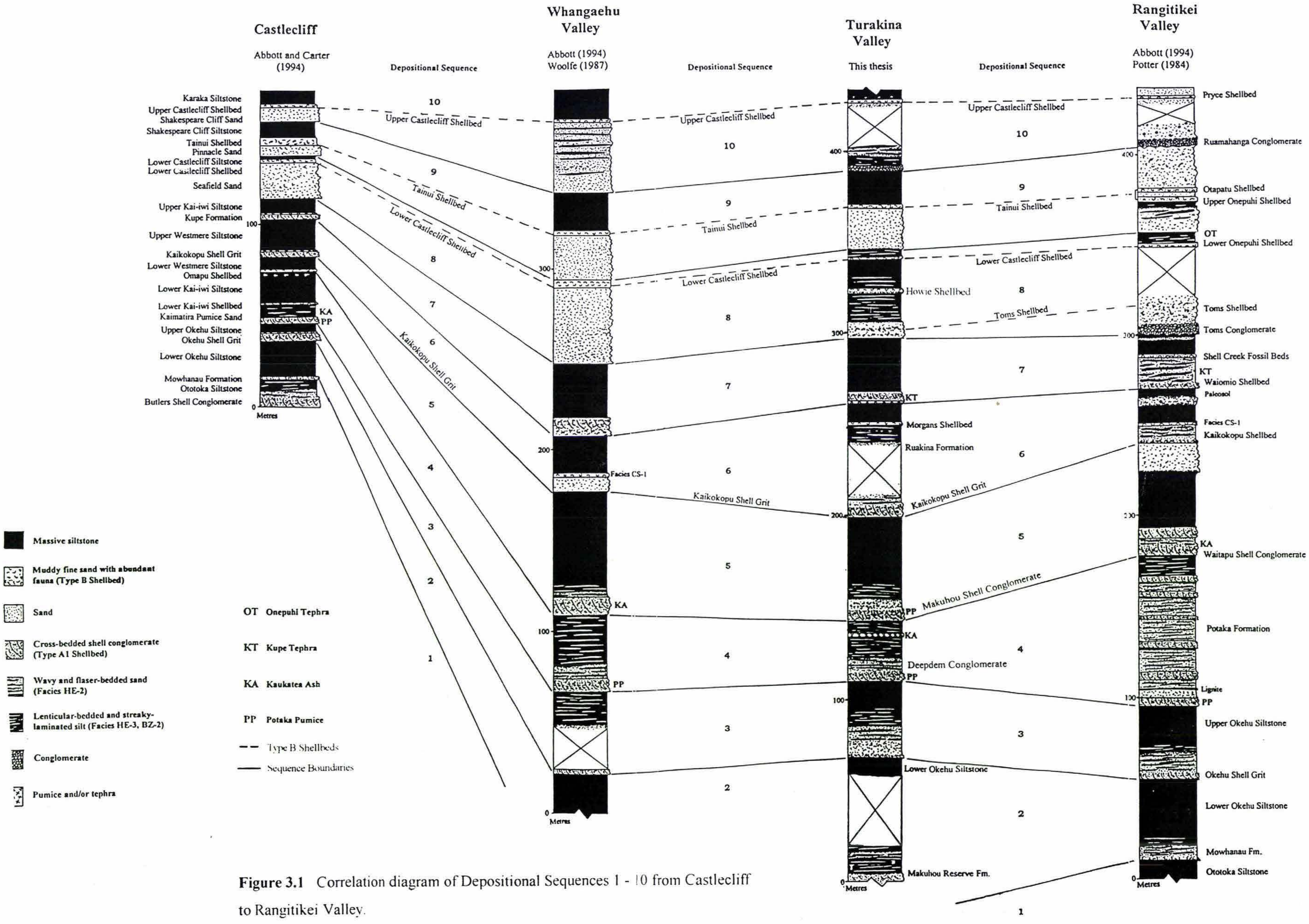


Figure 3.1 Correlation diagram of Depositional Sequences 1 - 10 from Castlecliff to Rangitikei Valley.

(40 000 yr cycles) to 5th Order (100 000 yr cycles) with an increase in amplitude of cycles.

Mid-cycle shellbeds which are formed in response to a rapid deepening as the depocentre moves landward during relative sea-level rise, tend to thin out or do not occur at all towards the east of the basin. This is consistent with higher sediment supply to these sites due to closer proximity to the uplifting axial ranges and Taupo Volcanic Zone. Sedimentation rate therefore decreased with distance from the ranges and sediment starved conditions necessary for condensed shellbed development, occurred mainly at the more distal Castlecliff section. It may be expected that with increased subsidence rates would come greater rates of relative sea-level rise, thereby creating more ideal conditions for sediment starvation. However, it is more likely in this instance that higher sedimentation rates kept pace with sea-level rise which meant that the shelf was rarely starved of sediment.

3.2 Trends in Turakina Valley

In this study, four new formations have been recognised within Turakina Valley:

Depositional Sequence 2 (Makuhou Reserve Formation)

A thick sequence of heterolithic facies representing the TST for Depositional Sequence 2 has previously not been described in Turakina or elsewhere and was therefore given a name based on location of the best exposed outcrop near Makuhou Reserve along Makuhou Road. Depositional Sequence 3 shows a similar trend and in hindsight, it may have been best to rename the formations accordingly.

Depositional Sequence 6 (Ruakina Formation and Morgans Shellbed)

The Kaikokopu Shell Grit is the basal member of the Ruakina Formation in Turakina Valley. A thick unit, composed largely of small - scale heterolithic facies was identified overlying the Kaikokopu Shell Grit member and combined, they represent the TST for

Depositional Sequence 6. The newly recognised unit was named the Ruakina Formation after the farm on which it was observed.

The Morgans Shellbed overlies the Ruakina Formation and represents the MCS for Depositional Sequence 6. Such a well formed mid-cycle shellbed has previously not been described in Turakina Valley or elsewhere across the basin. The Morgans Shellbed is distinctive because of its basal conglomerate followed by a muddy phase and/or high pebble content within a muddy shellbed.

Depositional Sequence 8 (Howie Shellbed etc.)

Formations that make up Depositional Sequence 8 in Turakina Valley are quite different to those elsewhere across the basin. The Seafield Sand formation which represents the TST for Depositional Sequence 8, is a thick sequence made up largely of small - scale heterolithic facies (Facies HE-2 and HE-3). The Seafield Sand is overlain by the Howie Shellbed, which like the Morgans Shellbed at some locations, consists of a pebbly basal shell conglomerate followed by a muddy shellbed. This shellbed has not been observed elsewhere in the Wanganui Basin sequences. The overlying siltstone unit is correlated with the Lower Castlecliff Siltstone and the name was retained for the Turakina Valley section. The Lower Castlecliff Shellbed lies within this siltstone formation In Turakina Valley and the unit of the Lower Castlecliff Siltstone which overlies the shellbed is made up of small - scale heterolithic facies (Facies HE-2 and HE-3). The shellbed and overlying facies most likely represent a period of shallowing either caused by a relative sea-level fall or uplift of the Marton Anticline.

When comparing these four depositional sequences, it can be seen that all have an anomalously thick TST composed largely of small - scale heterolithic facies. This feature occurs only in Turakina Valley, noticeably Depositional Sequences 2 and 6, and therefore a possible interpretation is that this reflects uplift of the Marton Anticline. The rate of uplift of the anticline kept pace with the rising sea level, allowing a thick sequence of shallow water facies to accumulate throughout a large part of the sea-level cycle.

The mid-cycle shellbeds within both Depositional Sequences 6 and 8 may mark the point at which the anticline ceased to be uplifted, initially reflected in reworking of pebbly innermost shelf facies, overlain by a muddy shellbed indicative of rapid deepening as sea-level continued to rise. This may also explain the very erosive lower contact at the base of the shell conglomerate.

An alternative interpretation to that of anticline uplift is that the Rangitikei River, or some other major sediment source, flipped west of the Marton Anticline introducing a greater sediment load into this part of the basin.

Further evidence that may support the interpretation of uplift along the Marton Anticline during the Plio-Pleistocene can be seen within the lower sandy unit of the Seafield Sand slightly NW of Howie Road, where a shellbed with very shallow water fauna overlies a shellbed with deeper water fauna.

Another trend in the Turakina Valley section is that the Type B Shellbeds generally have a more diverse and shallower water faunal assemblage compared to the mid-cycle shellbeds at Castlecliff. This is attributed to higher uplift rates towards the east of the basin due to closer proximity to the uplifting axial ranges and greater sand content may account for the more diverse nature of the faunal assemblage.

3.3 Pecten Zones

A *Pecten* correlation diagram is included in this section (**Figure 3.2**) and is a combination of work from Fleming (1957) (see Figures 2.1.5 and 2.1.6), Potter (1984), Woolfe (1987) and this thesis. In regards to the Turakina Valley section some differences from Fleming's work were found. Fleming based his zoning of *Pectens* on the occurrence of only one subspecies occurring within each zone. However, the occurrence of more than one subspecies (e.g. Tainui Shellbed, Ruakina Formation) per zone as observed in both Turakina Valley (this work) and Whangaehu Valley (Woolfe, 1987), indicates that the evolutionary progression of the species was more complex than Fleming suggests.

In the Turakina section and other sections across the basin, the base of the Upper Marwicki Zone was placed at the base of the Shakespeare Cliff Sand. The narrow Toi Zone placed at the top of the Pinnacle Sand in the Castlecliff section and just below the Onepuhi Shellbeds in Rangitikei Valley was absent in Turakina Valley. However, *Pecten tainui* and *Pecten toi* were both found within the Tainui Shellbed in Turakina Valley and in Whangaehu Valley forming a combined Tainui/Toi Zone. This could equally be named the Tainui/Toi/Jacobaeus Zone in Turakina Valley due to the presence of a new subspecies which closely resembles the Mediterranean *jacobaeus* subspecies (Beu pers. comm., 1995). Therefore, three subspecies representing three different evolutionary phases occur within the same time frame. The base of the Tainui zone was placed at the base of the Tainui Shellbed **(Figure 3.2)**.

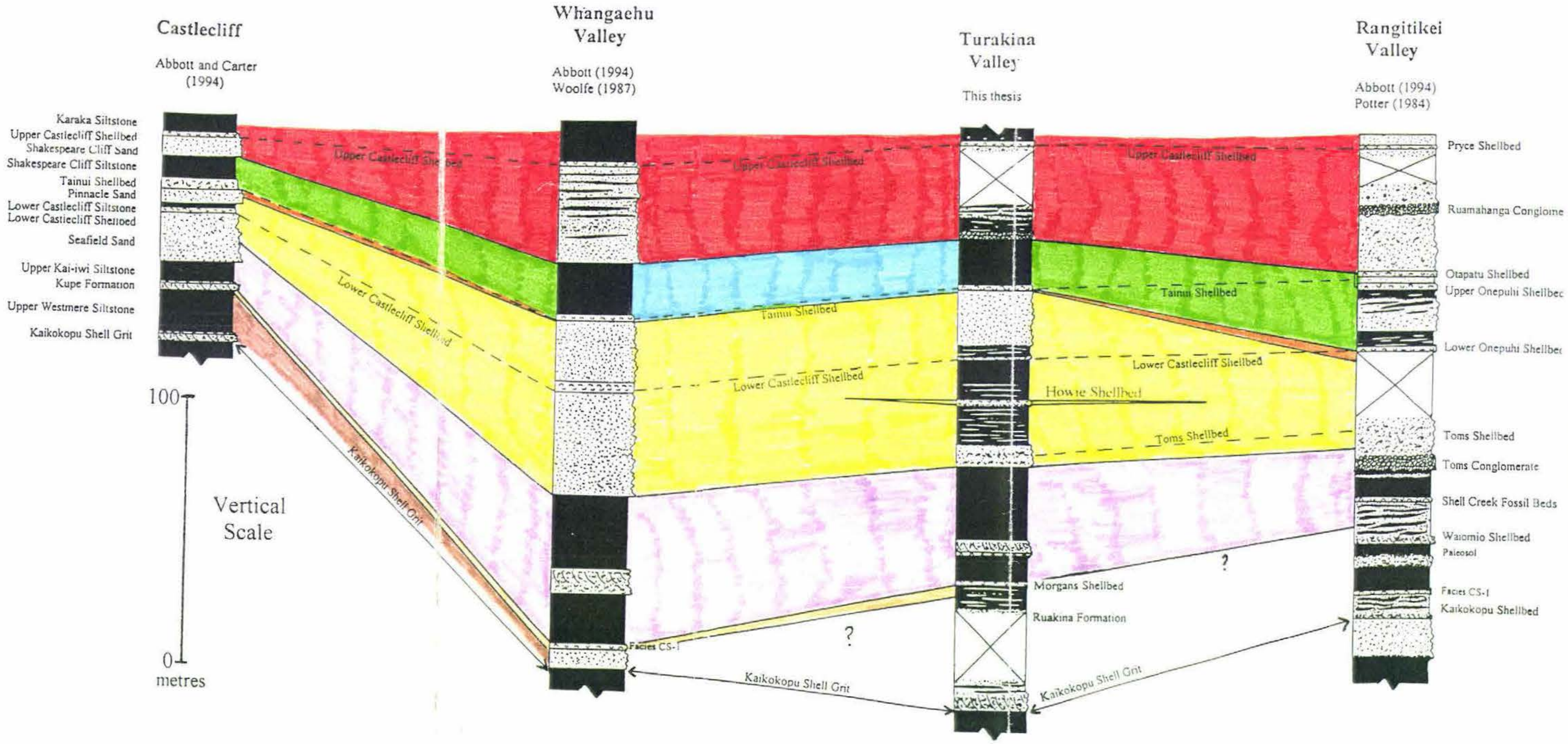
The base of the Lower Marwicki Zone was positioned at the base of the Seafield Sand in the Turakina Valley section due to the occurrence of *Pecten marwicki* within a shellbed located near the lower contact of this formation. At Castlecliff, the base of the Lower Marwicki Zone lies mid way within the Seafield Sand and the upper limit of the zone lies near the top of the Pinnacle Sand. In Rangitikei Valley the base of the zone lies just above the Toms Conglomerate and the upper limit is near the base of the Lower Onepuhi Shellbed **(Figure 3.2)**.

The base of the Kupei Zone in Turakina Valley was placed at the base of the Morgans Shellbed in accordance with the occurrence of *Pecten kupei* within this formation. The base of the Kupei Zone at Castlecliff was placed at the base of the Kupe Formation and in Rangitikei Valley was placed just above the Waiomio Shellbed. At Castlecliff the upper limit of the zone is positioned mid way within the Seafield Sand and at Rangitikei Valley, just above the Toms Conglomerate.

A narrow zone of *Pecten marwicki* was observed just below the Morgans Shellbed within the uppermost Ruakina Formation and is assigned to the Waikopiroensis Zone.

Some abraded subspecies of *Pecten* found within this formation resembled those found within the Upper Westmere Siltstone at Castlecliff and other subspecies found resembled *Pecten novaezelandiae* found within the Waiomio Shellbed in Rangitikei Valley, linking the Turakina section to both Castlecliff and Rangitikei sections. The occurrence of *Pecten* within the Ruakina Formation marks the FAD for the species in Turakina Valley.

The FAD of *Pecten* at Castlecliff occurs within the Upper Westmere Shellbed which lies just above the Kaikokopu Shell Grit. In Whangaehu Valley, this shellbed containing *Pecten* lies some 10 m above the Kaikokopu Shell Grit and at Rangitikei a coeval shellbed lies approximately 15 m above the Kaikokopu Shell Grit. In Turakina Valley, the shellbed containing the first appearance of *Pecten* species, is located at least 25 m above the Kaikokopu Shell Grit due to the anomalously thick TST of this depositional sequence.



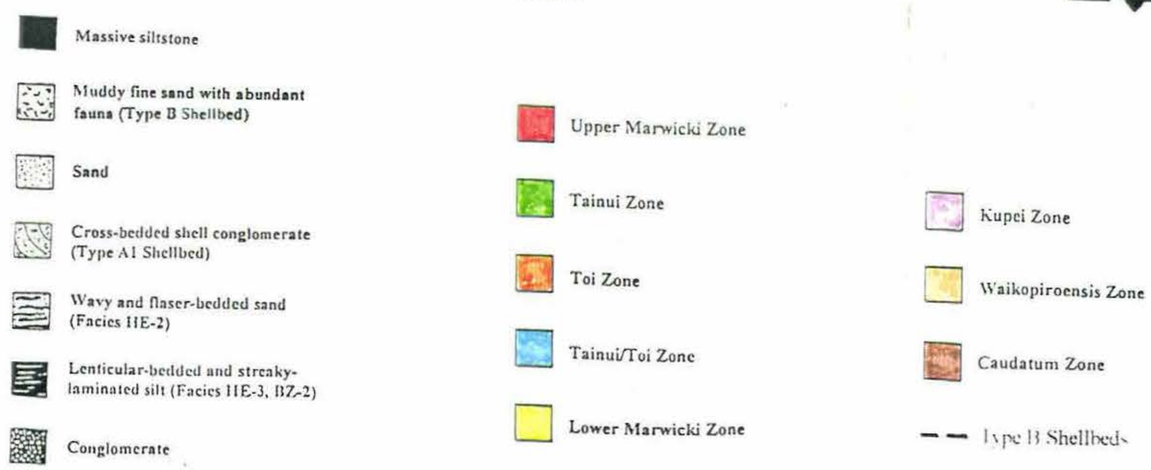


Figure 3.2 *Pecten* zone correlations from Castlecliff to Rangitikei Valley (based on the work of Fleming (1957), Woolfe (1987) and Potter (1984). *Pecten* information in the Turakina section is from this thesis only.

3.4 Facies Classification

The facies classification used in this thesis was based largely on the work of Abbott (1994) in accordance with the sequence stratigraphic interpretation of Carter *et al* (1991) and Abbott and Carter (1994) for the Wanganui Basin sedimentary cycles. In general, most of the facies described at Castlecliff persist across the basin to Rangitikei Valley, although in Turakina Valley, some facies were different enough to warrant their renaming. This is particularly the case with the Condensed Shellbed Association in Turakina Valley where facies have been classified on the basis of the appearance of the shellbed rather than different faunal assemblages. A list of dominant faunal species showing number of shellbed samples each species occurs in, is included in **Figure 3.3** and is summarised from a complete faunal list of all Type B Shellbed samples presented in **Appendix E**. The faunal assemblage is similar to that presented from Castlecliff mid-cycle shellbeds but overall indicates deposition in more shallow water conditions (Beu pers. comm., 1995). The five most commonly occurring species in **Figure 3.3** were also commonly noted at Castlecliff. The relatively common occurrence of *Amalda (Baryspira) mucronata, Felaniella zelandica, Glycymeris modesta, Antisolarium egenum, Zegalerus tenuis, Myadora striata, Leucotina ambigua, Xymene plebeius* and *Xymene pusillus* **(Figure 3.3)** in Turakina Valley Type B Shellbeds is different to assemblages from Castlecliff. The interpretation of this is not certain at this point.

After traversing the Castlecliff section twice, I noted Type A1 Shellbeds (Facies HE-1) there were thinner and not as well expressed in terms of sedimentary structures to those observed within the Turakina Valley section. The cause may be due to higher sedimentation rates than at Castlecliff, and/or to a steeper paleoshelf, where sediment was deposited in deeper water where tides affected sedimentation. The faunal assemblages of these base of cycle shellbeds in Turakina Valley is similar to that described for Type A1 Shellbeds at Castlecliff. A list of common occurrence of individual species for Type A1 Shellbeds in Turakina Valley is presented in **Figure 3.3** and was summarised from a complete faunal list included in **Appendix E**. The diagrams show that many species which commonly occur in Type B Shellbeds are also present in the Type A1 Shellbeds in Turakina Valley and may suggest that the two environments where these shellbeds occur were positioned close together on the shelf in this part of the basin.

Type A1 Shellbeds

Most Common Macrofauna	Occurrence (N = 7) 3	4	5	6	7
Pleuromeris zealandica	■	■	■	■	■
Tiostrea chilensis lutaria	■	■	■	■	■
Amalda (G.)	■	■	■	■	■
Maoricolpus roseus	■	■	■	■	■
Glycymeris modesta	■	■	■	■	
Paphies n. sp.	■	■	■	■	
Talochlamys gemmulata	■	■	■	■	
Tawera spissa	■	■	■	■	
Amalda (Baryspira)	■	■	■	■	
Leucotina ambigua	■	■	■	■	
Zethalia zelandica	■	■	■	■	
Antalis nana	■	■	■	■	
Purpurocardia purpurata	■	■	■		
Neoguraleus sp.	■	■	■		
Pelicaria vermis	■	■	■		
Penion sp.	■	■	■		
Trochus tiaratus	■	■	■		
Xymene expansus	■	■	■		
Zegalerus tenuis	■	■	■		
Maorimactra n. sp.	■	■			
Alcithoe arabica	■	■			
Pervicacia tristis	■	■			
Stiracolpus aff. symmetricus	■	■			
Xymene ambiguus	■	■			
Zeacolpus vittatus	■	■			

Type B Shellbeds

Most Common Macrofauna	Occurrence (N = 10) 5	6	7	8	9	10
Tawera spissa	■	■	■	■	■	■
Pleuromeris zealandica	■	■	■	■	■	
Purpurocardia purpurata	■	■	■	■	■	
Tiostrea chilensis lutaria	■	■	■	■	■	
Maoricolpus roseus	■	■	■	■	■	
Carycorbula zelandica	■	■	■			
Amalda (Baryspira)	■	■	■			
Sigapatella novaezelandiae	■	■	■			
Bryozoa	■	■	■			
Chlamys gemmulata	■	■				
Felaniella zelandica	■	■				
Glycymeris modesta	■	■				
Pecten sp.	■	■				
Amalda (G.) novaezelandiae	■	■				
Antisolarium egenum	■	■				
Austrofusus glans	■	■				
Trochus tiaratus	■	■				
Zegalerus tenuis	■	■				
Waltonia inconspicua	■					
Myadora striata	■					
Scalpomactra scalpellum	■					
Antimelatoma buchanani	■					
Leucotina ambigua	■					
Xymene plebeius	■					
Xymene pusillus	■					
Zeacolpus vittatus	■					
Antalis nana	■					

Figure 3.3 Summary table showing most common (occurring in more than half the samples collected) macrofauna which occur in Type A1 and Type B Shellbeds.

3.5 Paleoenvironmental Reconstruction

The sea-level cycles that occurred during the Plio-Pleistocene were subject to a variety of influences aside from glacio - eustatic forces. In the Turakina Valley sequence, these influences mainly originate from increases in sediment supply into the basin or uplift of the Marton Anticline, and shelf geomorphology at the time of deposition. These factors are reflected most strongly above wave base in the deposits that represent the transgressive systems tracts of the depositional sequences.

The base of TST's for Depositional Sequences 2, 3, 8, 9, and 10 are made up of facies that represent deposition mainly in the shoreface environment. The dominance of shoreface facies at the base of each of these depositional sequences suggests that the shelf at those times maintained very shallow conditions for quite an extensive distance down the shelf. Sedimentation was more dominantly affected by longshore drift, as indicated by paleocurrent data from the Okehu Shell Grit (Depositional Sequence 3). These basal deposits are overlain by facies which represent deposition in slightly deeper water in the transition zone between the shoreface and innermost shelf and within the innermost shelf environment, in response to a rising sea level.

The basal unit of TST's for Depositional Sequences 4, 5, 6 and 7 is made up of facies that represent deposition on the innermost shelf. This dominance of innermost shelf facies directly overlying the sequence boundary indicates a steeply sloping shelf where the shoreface zone may be very narrow or may not occur at all. Paleocurrent data from the Deepdem Conglomerate (Potaka Pumice) member of the Kaimatira Pumice Sand and from the Kaikokopu Shell Grit member of the Ruakina Formation, indicate that sedimentation was strongly affected by tides during these periods.

The Kaikokopu Shell Grit was described from many locations within the study area and consists of facies representing deposition in both the shoreface and innermost shelf environments. These rapid lateral facies changes indicate that the shoreline during this event, and perhaps others, was more diverse than the coastline of today. The occurrence of semi enclosed or open bays may have been more common during some periods within the Plio-Pleistocene, giving the coastline a more wavy appearance rather than the more or less uninterrupted curve that is evident today.

The formation of tide - dominated deltas, represented by anomalously thick TST's in Depositional Sequences 2, 3, 4, 6 and 8 in the Turakina Valley section, was common during the Plio-Pleistocene. The formation of a delta during the deposition of the Kaimatira Pumice Sand (Depositional Sequence 4) is attributed to a large eruptive event from the Taupo Volcanic Zone which increased the sediment supply into the basin throughout much of the sea-level cycle. Formation of a delta (represented), during deposition of the TST's of Depositional Sequences 2, 3, 6 and 8 is attributed to either uplift of the Marton Anticline or to the diversion of a major sediment source into the depositional site, which allowed the accumulation of a thick unit of small - scale heterolithic facies during a large part of the sea-level cycle.

3.6 Volcanic Marker Beds

Volcanic marker beds that occur within the Plio-Pleistocene are becoming increasingly well dated (Pillans *et al*, 1994). Pillans *et al* (1994) provided an important date for the Potaka Pumice of c. 1 Ma which is older than previously documented. The Potaka Pumice is perhaps the most significant and easily recognisable unit in the Wanganui Basin sequences, indicating the occurrence of a very large eruptive event. It is seen at its thickest in the Rangitikei Valley indicating that the headwaters of the Rangitikei River were at that time also in close proximity to the Taupo Volcanic Zone. Although the unit is thinner in the Turakina Valley section, the pumice is reworked through successive formations (Makuhou Shell Conglomerate, (?) Kaikokopu Shell Grit). The Kupe Tephra and Kaukatea Ash were also identified in the Turakina Valley section where the Kaukatea Ash was also reworked as pumice in a successive formation (Kupe Formation). The procedure for identification of the tephras is included in **Appendix A**.

The Potaka Pumice clearly occurs within the Kaimatira Pumice Sand (Deepdem Conglomerate) (samples T16, T31) and was also identified within the Makuhou Shell Conglomerate as reworked pumice (sample T40) **(Figure 3.4, Appendix A)**. The Kaimatira Pumice Sand formation on Taurimu Road is unusual in that the Potaka Pumice member consists of three distinct units; a basal pumice grit (sample T27), a central white tephra (sample T28) and an overlying pumiceous conglomerate (sample T 29). Sample T 29 was similar in chemical composition to the Potaka Pumice but samples T27 and T28 were less so. However, when plotted on a ternary diagram samples T 27 and T 28 lie in a position consistent with that of the Potaka Pumice **(Figure 3.4)**. These units are interpreted to be water transported rather than wind transported because of the occurrence of faint bedding structures observed in the fine, white tephra and underlying pumiceous grit.

The Kaukatea Ash was seen as a discrete 0.3 - 0.7 m ash layer within the upper Kaimatira Pumice Sand on the farm at the upper end of Morgans Road. The tephra was not sampled due to the inaccessible nature of the outcrop. However, its stratigraphic position within the upper unit of the Kaimatira Pumice Sand clearly indicates that it is the Kaukatea Ash.

The Kupe Tephra occurs as a tephric fine sand and pumiceous grit (sample T 10) near the base of the Kupe Formation in Turakina Valley. Pumice taken from the basal unit of the Kupe Formation at another site (sample T 11) showed a stronger similarity to the Kaukatea Ash **(Figure 3.4, Appendix A)** which was most likely reworked and deposited as part of this unit.

Pumice taken from the Kaikokopu Shell Grit (sample T 39) was not able to be identified and may be of mixed population. However, when the normalised data as a whole was plotted on a ternary diagram **(Figure 3.4)**, the tephra lies within the acceptable range of the Potaka Pumice and may be a reworked form of this tephra.

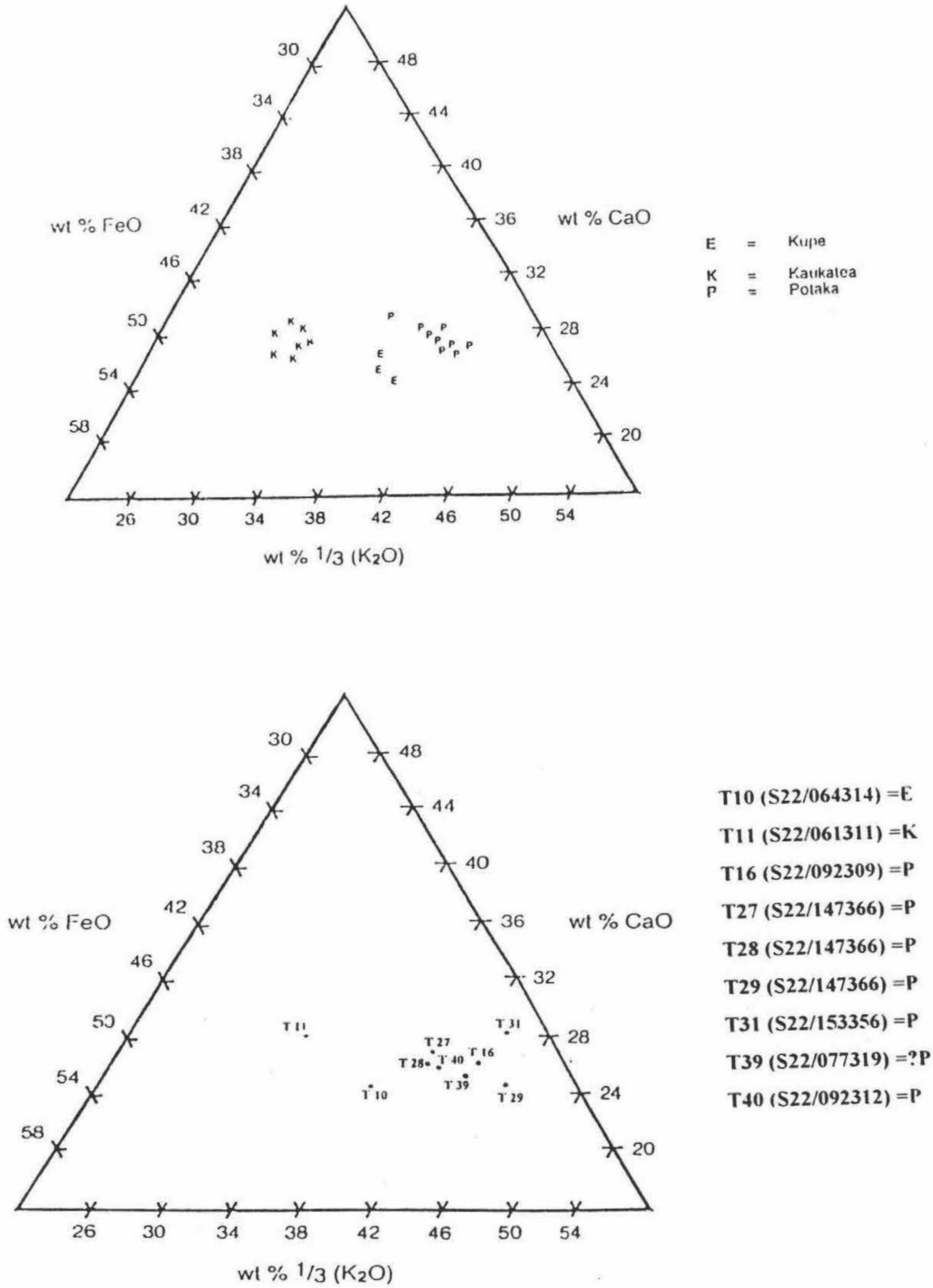


Figure 3.4 CaO - FeO - 1/3 K2O plots from electron microprobe analysis of rhyolite glass shards from: A) Wanganui Basin (Pillans *et al*, 1994), B) Turakina Valley (this work).

3.7 Summary

- Ten depositional sequences comprise the Plio-Pleistocene marine sequence in Turakina Valley. Deposition was largely controlled by glacio - eustatic changes in sea level.

- Turakina Valley depositional sequences are correlated closely to those at Castlecliff, Whangaehu Valley and Rangitikei Valley.

- The depositional sequences correspond to the Sequence Stratigraphic Model, in that sequences can be sub - divided into 3 facies successions (systems tracts) and mid-cycle shellbed, between sequence bounding surfaces. A typical sequence consists of transgressive, mid - cycle condensed shellbed and highstand systems tracts. The systems tracts are divided by two mid - cycle unconformities; the Local Flooding Surface and Downlap Surface. Lowstand sediments are not represented in the Wanganui Basin sequence due to wave planation caused by a rising sea level, with the exception of one occurrence in Rangitikei Valley.

- Facies successions in the transgressive systems tract typically start with a basal cross - bedded shell conglomerate (Type A1 Shellbed), followed by sediments deposited within shoreface - innermost shelf environments (Heterolithic and Sandstone Associations). The transgressive systems tract of the depositional sequences in Turakina Valley are generally thicker than those at the Castlecliff section and this is attributed to increased sediment supply towards the east of the basin. The greater sediment supply is attributed to closer proximity to sediment sources to the east (axial ranges) and north (Taupo Volcanic Zone).

- Mid - cycle condensed shellbeds comprise relatively thin, transgressive successions, and are made up of facies of the Condensed Shellbed Association. The Mid - cycle Condensed Shellbed corresponds to a Type B Shellbed and is formed on the inner shelf when sediment supply is negligible. In Turakina Valley the Mid - cycle

Condensed Shellbeds were classified on the basis of appearance in terms of lithology, fabric and bounding surfaces. In general, the Mid - cycle shellbeds in Turakina Valley are thinner and contain shallower water and more diverse fauna than those at the Wanganui coast. This is attributed to the greater sedimentation rate towards the east of the basin and the sandier nature of Type B Shellbeds.

- The mid - cycle unconformities bounding the base and top of Mid - cycle Condensed Shellbed successions (LFS and DLS) are both transgressive surfaces. Local Flooding Surfaces form by omission of terrigenous sediment and submarine erosion, at the distal Transgressive Systems Tract. The Downlap Surface marks the point of reactivation of sedimentation due to an enlarging depocentre as the sea nears its point of maximum flooding.

- The Highstand Systems Tracts are represented by relatively thick accumulations of siltstone. Successions are incomplete and truncated by the sequence - bounding ravinement surfaces. In Turakina Valley, the HST of depositional sequences are up to 5 - fold thicker than those at Castlecliff reflecting increased sediment supply and increased subsidence rates towards the east of the basin.

- The identification of *Pecten* zones by Fleming (1957) has aided to some extent in determining the identity of Mid - cycle shellbeds in Turakina Valley. The *Pecten* subspecies appear more diverse in Turakina Valley than Fleming's initial interpretation, perhaps indicating a more complex zoning than previously thought.

- Evidence of uplift of the Marton Anticline during the Plio-Pleistocene may be seen within at least four of the depositional sequences (2, 3, 6 and 8) in Turakina Valley. TST's are anomalously thick and made up largely of small - scale heterolithic facies, indicating that uplift balanced sea-level rise, maintaining shallow conditions. Deposition of these facies most likely occurred along the upper flank of the anticline where uplift was more pronounced. An alternative interpretation is that a major sediment source was diverted to this part of the basin during certain periods. In response to this, the HST's of these depositional sequences tend to be relatively thin compared to other depositional sequences in the Turakina Valley section and the other sections across the basin with the exception of the Rangitikei valley section which is dominated by shallow water facies for different reasons.

- Sedimentation on the paleoshelf was subject to a variety of influences other than fluctuating sea-level. Shifting sediment supply and/or uplift of the Marton Anticline in Turakina Valley, and the geomorphology of the shelf at the time of deposition, also affected sedimentation.

- Rapid facies changes observed in the Kaikokopu Shell Grit in Turakina Valley may indicate that the paleocoastline during this, and possibly other events during the Plio-Pleistocene, was much more diverse than that of today.

- Volcanic marker beds, particularly the Potaka Pumice, provide good age constraints for the Wanganui Basin sequence.

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APPENDICES

Appendix A - Tephra Analysis

Procedure

Small samples of airfall tephra and crushed pumice clasts (sieved to 250-63 microns grain size) were separated into magnetic and non-magnetic fractions using the Franz Magnetic Separator. The sample of non-magnetic minerals containing predominantly volcanic glass, was mounted on a slide. Once ground to an appropriate thickness, the slide was polished to produce a smooth surface. At least 9 glass shards from each sample were chemically analysed using the JEOL JXA - 733 Electron Microprobe housed in the Geology Department at Victoria University, Wellington. Nine elements were chosen for the chemical analysis; SiO2, TiO2, Al2O3, FeO, MgO, CaO, Na2O, K2O, Cl. A 20 micron beam diameter and 80nA beam current were used for all analyses. All microprobe data was normalised and compared with chemical analyses of other known tephras which were analysed using the same microprobe settings.

Some samples (e.g. T 39, T 40) showed mixed populations of pumice. Like-values of FeO and CaO were grouped, meaned and again chemically compared to other, known tephras. Microprobe data, normalised data and similarity coefficients for each tephra sample are presented in this appendix.

Known Tephras used for comparisons

KupeC	Kupe Tephra	0.45+/- 0.009 Ma (Pillans *et al* 1994)
KaukateaC	Kaukatea Ash	0.57+/- 0.08 Ma (Pillans *et al* 1994)
PotakaD	Potaka Pumice	1.05+/- 0.05 Ma (Pillans *et al* 1994)
RewaE	Rewa Pumice	0.74+/- 0.09 Ma (Pillans *et al* 1994)
MangapipiC	Mangapipi Ash	0.88+/- 0.13 Ma (Pillans *et al* 1994)
PakikihuraE	Pakikihura Pumice	1.63+/- 0.15 Ma (Pillans *et al* 1994)
MangahouE	Mangahou Ash	1.26+/- 0.17 Ma (Pillans *et al* 1994)

'ephra: T 10

)escription: pumiceous grit (Kupe Formation)

}rid Reference: S: S22/064314

licroprobe Data

10	1	2	3	4	5	6	7	8	9	10	11	12	13	14
IO2	74.02	73.71	72.89	71.55	72.46	72.50	73.73	72.43	73.05	71.12	72.96	72.30	73.63	74.15
iO2	0.16	0.16	0.13	0.20	0.21	0.16	0.12	0.09	0.16	0.16	0.11	0.21	0.15	0.12
l2O3	12.14	11.93	11.12	11.76	11.79	11.67	11.60	11.72	12.28	11.70	11.95	11.60	11.62	11.37
eO	1.30	1.24	1.07	1.11	1.54	1.45	1.18	1.36	1.25	1.14	1.26	1.50	1.14	1.09
lgO	0.17	0.07	0.14	0.11	0.09	0.13	0.08	0.13	0.12	0.14	0.11	0.13	0.09	0.10
aO	0.96	0.69	0.60	0.87	0.87	0.89	0.69	0.83	0.99	0.73	0.85	0.95	0.73	0.66
la2O	3.97	3.91	3.61	3.43	3.81	3.98	4.00	3.73	4.10	3.81	3.84	3.88	3.83	3.58
2O	3.58	3.94	3.55	4.12	3.54	3.50	3.92	3.46	3.42	3.60	3.63	3.39	3.83	3.76
l	0.14	0.15	0.17	0.14	0.10	0.13	0.14	0.14	0.11	0.15	0.14	0.13	0.15	0.16
otal	96.43	95.79	93.29	93.28	94.40	94.40	95.46	93.89	95.48	92.53	94.84	94.08	95.16	94.98

ormalised Data

															Mean
IO2	76.76	76.95	78.13	76.70	76.76	76.80	77.24	77.14	76.51	76.86	76.93	76.85	77.38	78.07	77.08
iO2	0.17	0.17	0.14	0.21	0.22	0.17	0.12	0.10	0.16	0.17	0.11	0.22	0.15	0.12	0.16
l2O3	12.59	12.45	11.92	12.60	12.49	12.36	12.15	12.48	12.86	12.64	12.60	12.33	12.22	11.97	12.40
eO	1.35	1.30	1.15	1.19	1.63	1.54	1.24	1.45	1.31	1.23	1.32	1.59	1.20	1.14	1.33
lgO	0.18	0.08	0.15	0.12	0.09	0.13	0.09	0.14	0.13	0.15	0.11	0.14	0.09	0.10	0.12
aO	0.99	0.72	0.65	0.93	0.92	0.94	0.72	0.89	1.04	0.79	0.90	1.01	0.76	0.69	0.85
a2O	4.11	4.08	3.87	3.67	4.04	4.22	4.19	3.97	4.30	4.12	4.05	4.12	4.03	3.76	4.04
2O	3.71	4.11	3.81	4.41	3.75	3.70	4.11	3.68	3.59	3.89	3.83	3.61	4.02	3.96	3.87
l	0.14	0.15	0.18	0.15	0.10	0.14	0.15	0.15	0.12	0.16	0.15	0.14	0.15	0.17	0.15
otal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

imilarity Coefficients

upeC	KaukateaC	PotakaD	RewaE	T11
939	0.859	0.869	0.841	0.927

'eans of normalised data were run against normalised data from Pillans et al (1994) ephra: T11

escription: pumice in sand (Kupe Formation)

rid Reference: S22/061311

licroprobe Data

11	1	2	3	4	5	6	7	8	9
iO2	71.20	72.80	73.81	71.72	72.02	73.26	72.77	73.69	72.40
O2	0.22	0.09	0.21	0.13	0.21	0.21	0.11	0.10	0.12
l2O3	12.72	11.47	11.61	12.46	12.32	12.20	11.95	11.45	12.54
eO	1.86	1.24	1.15	1.47	1.40	1.42	1.15	1.17	1.70
gO	0.23	0.14	0.11	0.17	0.13	0.13	0.15	0.05	0.14
aO	1.28	0.84	0.79	1.13	1.08	0.89	0.92	0.69	1.10
a2O	4.35	3.72	3.64	4.37	4.24	3.91	3.88	3.21	4.51
2O	2.91	3.51	3.76	3.22	3.20	3.48	3.58	4.34	3.27
	0.13	0.17	0.10	0.13	0.11	0.18	0.12	0.16	0.14
otal	94.89	93.97	95.18	94.80	94.72	95.67	94.63	94.86	95.91

ormalised Data

										Mean
O2	75.03	77.48	77.55	75.66	76.04	76.58	76.90	77.69	75.48	76.44
O2	0.23	0.09	0.22	0.14	0.23	0.22	0.11	0.10	0.13	0.17
2O3	13.41	12.20	12.20	13.15	13.00	12.76	12.63	12.07	13.08	12.77
eO	1.96	1.32	1.20	1.55	1.48	1.48	1.21	1.23	1.77	1.45
gO	0.24	0.14	0.12	0.18	0.13	0.13	0.16	0.06	0.14	0.16
aO	1.35	0.89	0.83	1.19	1.14	0.93	0.98	0.73	1.14	1.06
a2O	4.58	3.96	3.82	4.61	4.48	4.09	4.10	3.38	4.71	4.26
2O	3.06	3.74	3.95	3.39	3.38	3.63	3.79	4.57	3.41	3.55
	0.13	0.18	0.10	0.14	0.12	0.19	0.13	0.17	0.15	0.13
otal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

milarity Coefficients

KupeC	*KaukateaC	*PotakaD	*RewaE	T10
0.889	0.928	0.813	0.905	0.927

Normalised data from Pillans et al 1994

ephra: T 16

escription: Pumiceous sand (Deepdem Conglomerate member of the Kaimatira Pumice Sand)

rid Reference: S22/092309

icroprobe Data

16	1	2	3	4	5	6	7	8	9	10
IO2	74.14	74.13	73.31	75.01	75.07	74.15	75.63	75.00	75.04	75.65
O2	0.15	0.13	0.14	0.06	0.08	0.16	0.08	0.07	0.07	0.11
l2O3	12.05	12.18	12.20	11.73	12.47	12.03	12.19	12.71	11.83	11.98
eO	1.27	0.90	0.97	0.87	1.04	0.90	0.93	1.24	0.91	0.96
gO	0.12	0.13	0.08	0.13	0.07	0.07	0.14	0.18	0.17	0.12
aO	1.04	0.85	0.89	0.68	0.75	0.66	0.80	1.13	0.70	0.81
a2O	3.60	3.67	3.52	3.71	3.65	3.51	3.68	3.46	3.58	3.62
2O	3.84	3.92	3.76	4.26	4.25	3.95	3.97	4.00	4.12	3.85
	0.12	0.15	0.15	0.20	0.16	0.14	0.12	0.16	0.16	0.15
otal	96.33	96.04	95.02	96.64	97.53	95.57	97.52	97.95	96.57	97.23

ormalised Data

											Mean
O2	76.97	77.19	77.15	77.61	76.97	77.59	77.55	76.57	77.70	77.81	77.31
O2	0.16	0.13	0.14	0.06	0.08	0.17	0.09	0.08	0.07	0.11	0.11
2O3	12.51	12.68	12.84	12.14	12.79	12.58	12.50	12.98	12.25	12.32	12.56
eO	1.31	0.94	1.02	0.90	1.07	0.94	0.95	1.27	0.94	0.99	1.03
gO	0.12	0.14	0.08	0.13	0.07	0.07	0.14	0.19	0.18	0.12	0.12
aO	1.08	0.88	0.94	0.70	0.77	0.69	0.82	1.15	0.72	0.83	0.86
a2O	3.73	3.82	3.71	3.84	3.74	3.68	3.77	3.53	3.71	3.72	3.72
2O	3.99	4.08	3.95	4.41	4.35	4.13	4.07	4.08	4.27	3.96	4.13
	0.12	0.15	0.16	0.20	0.16	0.14	0.12	0.16	0.16	0.15	0.15
otal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

milarity Coefficients

(upeC	KaukateaC	PotakaD	RewaE
0.904	0.794	0.939	0.773

ormalised mean run against normalised data from Pillans et al, (1994).

Tephra: T 27

Description: basal lapilli layer of airfall tephra (Kaimatira Pumice Sand)

Grid Reference: S22/147366

Microprobe Data

T27	1	2	3	4	5	6	7	8	9	10
SiO2	74.97	74.37	75.44	74.86	73.53	75.50	73.88	74.46	72.97	74.71
TiO2	0.16	0.17	0.10	0.07	0.16	0.13	0.14	0.22	0.16	0.19
Al2O3	11.76	11.76	12.23	11.68	11.97	11.93	11.81	11.50	12.62	12.06
FeO	1.10	1.03	1.12	0.91	1.14	1.17	1.26	0.97	1.87	1.04
MgO	0.25	0.21	0.01	0.10	0.25	0.17	0.22	0.19	0.27	0.15
CaO	0.93	0.94	0.73	0.69	1.02	0.94	1.06	0.86	0.98	0.98
Na2O	3.47	3.54	3.69	3.72	3.73	3.70	2.95	3.19	3.69	3.47
K2O	3.79	3.66	3.73	3.99	3.71	3.66	4.23	3.94	3.87	3.52
Cl	0.14	0.12	0.13	0.14	0.13	0.12	0.11	0.12	0.08	0.16
Total	96.56	95.79	97.16	96.15	95.63	97.32	95.66	95.45	96.52	96.28

Normalised Data

											Mean
SiO2	77.64	77.63	77.65	77.86	76.88	77.58	77.23	78.01	75.60	77.60	77.37
TiO2	0.17	0.17	0.10	0.07	0.17	0.14	0.15	0.23	0.17	0.19	0.16
Al2O3	12.17	12.27	12.59	12.14	12.52	12.26	12.34	12.04	13.08	12.53	12.39
FeO	1.14	1.08	1.15	0.95	1.19	1.20	1.32	1.02	1.94	1.08	1.21
MgO	0.26	0.22	0.01	0.10	0.26	0.18	0.23	0.20	0.28	0.15	0.19
CaO	0.96	0.99	0.75	0.71	1.07	0.96	1.11	0.90	1.02	1.02	0.95
Na2O	3.59	3.69	3.79	3.87	3.90	3.80	3.08	3.34	3.82	3.60	3.65
K2O	3.93	3.82	3.84	4.15	3.88	3.76	4.42	4.13	4.01	3.66	3.96
Cl	0.14	0.12	0.13	0.14	0.13	0.13	0.11	0.13	0.08	0.16	0.13
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity Coefficients

KupeC	`KaukateaC	`PotakaD	`RewaE	`MangapipiC	`PakihikuraE
0.900	0.859	0.854	0.84	0.819	0.834

`MangahouE	T 10	T 16	T29
0.853	0.914	0.875	0.875

` Normalised data from Pillans et al (1994).

Tephra: T28

Description: white ash (probably not airfall) (Kaimatira Pumice Sand)

Grid Reference: S22/147366

Microprobe Data

T28	1	2	3	4	5	6	7	8	9	10
SiO2	75.51	76.63	72.27	74.08	73.55	75.19	74.67	75.00	74.21	74.57
TiO2	0.18	0.14	0.09	0.11	0.16	0.16	0.18	0.05	0.13	0.10
Al2O3	11.92	12.24	11.56	11.88	11.90	11.80	11.45	11.71	11.87	11.91
FeO	1.29	1.39	1.08	1.14	0.88	1.23	1.10	1.14	0.93	1.04
MgO	0.17	0.17	0.18	0.11	0.25	0.16	0.07	0.35	0.01	0.32
CaO	0.90	0.83	0.88	0.77	0.71	0.92	1.02	0.72	0.78	0.84
Na2O	3.31	3.29	3.02	3.15	2.37	3.02	3.29	2.36	2.54	2.89
K2O	3.34	3.56	3.52	3.41	5.16	3.18	3.31	3.65	3.62	3.78
Cl	0.25	0.24	0.25	0.26	0.14	0.25	0.27	0.24	0.20	0.29
Total	96.88	98.48	92.86	94.91	95.11	95.90	95.36	95.22	94.28	95.74

Normalised Data

											Mean
SiO2	77.94	77.82	77.83	78.05	77.32	78.40	78.30	78.76	78.71	77.88	78.10
TiO2	0.19	0.14	0.09	0.12	0.17	0.17	0.19	0.06	0.14	0.10	0.14
Al2O3	12.31	12.43	12.45	12.51	12.51	12.30	12.01	12.30	12.59	12.43	12.38
FeO	1.33	1.41	1.17	1.20	0.93	1.28	1.15	1.20	0.99	1.09	1.17
MgO	0.17	0.17	0.19	0.11	0.26	0.16	0.08	0.37	0.01	0.34	0.19
CaO	0.93	0.85	0.95	0.81	0.74	0.96	1.07	0.76	0.83	0.87	0.88
Na2O	3.41	3.34	3.25	3.32	2.49	3.15	3.45	2.47	2.69	3.02	3.06
K2O	3.45	3.61	3.79	3.59	5.43	3.31	3.47	3.84	3.84	3.95	3.83
Cl	0.26	0.25	0.27	0.28	0.15	0.26	0.28	0.25	0.22	0.31	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity Coefficients

#Kupe	#Kauk. (	#Potak.	#Rewa	T 10	T 16	T 27	T 29	T 30	T 31	T 38
0.897	0.821	0.859	0.802	0.886	0.875	0.945	0.874	0.866	0.868	0.846

 # Normalised data from Pillans et al (1994)

Tephra: T 29

Description: reworked pumice in sand (Kaimatira Pumice Sand)

Grid Reference: S22/147366

Microprobe Data

T29	1	2	3	4	5	6	7	8	9	10	11
SiO2	75.20	74.53	73.96	74.60	74.72	75.68	74.20	76.05	74.74	74.49	74.59
TiO2	0.05	0.18	0.22	0.08	0.03	0.14	0.14	0.02	0.09	0.18	0.00
Al2O3	11.96	12.19	12.17	11.71	11.76	11.96	12.10	11.90	11.67	11.62	12.03
FeO	1.05	1.04	0.98	0.92	0.82	0.77	0.28	0.98	0.96	1.18	1.02
MgO	0.10	0.24	0.17	0.04	0.14	0.29	0.08	0.22	0.01	0.21	0.11
CaO	0.61	1.06	1.02	0.63	0.65	0.68	0.89	0.64	0.64	0.87	0.72
Na2O	3.66	3.60	3.67	3.61	3.75	3.68	2.89	3.68	3.22	3.66	3.70
K2O	4.33	3.77	3.60	4.23	4.03	4.30	4.42	4.39	4.69	3.62	3.95
Cl	0.13	0.15	0.13	0.10	0.14	0.16	0.12	0.13	0.13	0.12	0.12
Total	97.08	96.75	95.91	95.92	96.05	97.66	95.12	98.01	96.15	95.95	96.24

Normalised Data

												Mean
SiO2	77.46	77.03	77.11	77.77	77.80	77.50	78.00	77.60	77.73	77.64	77.51	77.56
TiO2	0.06	0.18	0.23	0.08	0.03	0.15	0.15	0.02	0.09	0.18	0.00	0.11
Al2O3	12.32	12.60	12.69	12.21	12.24	12.24	12.72	12.14	12.14	12.11	12.50	12.36
FeO	1.08	1.08	1.02	0.96	0.85	0.78	0.30	1.00	0.99	1.23	1.06	0.94
MgO	0.10	0.25	0.18	0.05	0.15	0.30	0.09	0.22	0.01	0.22	0.12	0.15
CaO	0.63	1.10	1.06	0.65	0.68	0.70	0.93	0.65	0.66	0.90	0.75	0.79
Na2O	3.76	3.72	3.82	3.76	3.90	3.77	3.04	3.75	3.35	3.82	3.84	3.69
K2O	4.46	3.89	3.75	4.41	4.20	4.40	4.65	4.47	4.88	3.77	4.11	4.27
Cl	0.13	0.16	0.13	0.10	0.15	0.16	0.13	0.13	0.13	0.12	0.13	0.13
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity Coefficients

KupeC	*PotakaD	*RewaE	*MangapipiC	*PakikihuraE
0.862	0.899	0.778	0.768	0.835

T 10	T 16	T 30	T 31	T 38
0.761	0.946	0.945	0.923	0.907

* Normalised data from Pillans et al (1994).

Tephra: T 31

Description: pumiceous sand (Kaimatira Pumice Sand)

Grid Reference: S22/153356

Microprobe Data

T31	1	2	3	4	5	6	7	8	9	10
SiO2	74.38	74.64	73.90	74.20	72.11	73.67	74.42	74.10	72.55	73.26
TiO2	0.04	0.15	0.17	0.09	0.16	0.12	0.12	0.12	0.15	0.09
Al2O3	11.75	11.60	12.08	11.92	12.14	11.78	12.01	11.88	11.67	11.52
FeO	0.65	0.43	0.98	0.89	1.47	0.66	1.18	0.99	0.97	0.25
MgO	0.08	0.09	0.11	0.08	0.11	0.12	0.15	0.08	0.08	0.12
CaO	0.94	0.89	0.85	0.99	1.01	0.93	0.92	0.66	0.73	0.67
Na2O	3.63	3.55	3.46	3.22	4.25	3.62	3.63	3.72	3.21	3.51
K2O	4.09	3.87	3.86	4.66	3.58	3.57	3.85	3.70	4.74	4.80
Cl	0.22	0.23	0.21	0.28	0.16	0.27	0.30	0.26	0.31	0.28
Total	95.79	95.44	95.63	96.32	94.99	94.74	96.56	95.50	94.40	94.48

Normalised Data

											Mean
SiO2	77.65	78.21	77.28	77.04	75.92	77.76	77.07	77.59	76.85	77.54	77.29
TiO2	0.04	0.16	0.18	0.09	0.17	0.13	0.12	0.12	0.16	0.09	0.13
Al2O3	12.27	12.15	12.63	12.38	12.78	12.43	12.44	12.44	12.36	12.19	12.41
FeO	0.68	0.45	1.02	0.92	1.55	0.70	1.22	1.04	1.02	0.26	0.89
MgO	0.08	0.09	0.11	0.08	0.11	0.13	0.15	0.08	0.08	0.13	0.11
CaO	0.98	0.93	0.89	1.03	1.06	0.98	0.95	0.69	0.77	0.71	0.90
Na2O	3.79	3.72	3.62	3.34	4.47	3.82	3.76	3.89	3.40	3.71	3.75
K2O	4.27	4.05	4.04	4.83	3.77	3.77	3.98	3.87	5.02	5.08	4.27
Cl	0.23	0.24	0.22	0.29	0.17	0.28	0.31	0.27	0.33	0.29	0.26
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity Coefficients

\`PotakaD	\`RewaE	\`MangapipiC	\`PakikihuraE	T 16	T 29	T 30
0.910	0.771	0.791	0.852	0.941	0.923	0.924

\` Normalised data from Pillans et al (1994).

Tephra: T 39

Description: pumice in sandy shell grit (Kaikokopu Shell Grit)

Grid Reference: S22/077319

Microprobe Data

T39	1	2	3	4	5	6	7	8	9	10	11
SiO2	76.32	74.65	75.09	73.24	75.41	74.91	75.64	74.17	74.54	72.25	74.37
TiO2	0.08	0.24	0.11	0.19	0.13	0.21	0.24	0.22	0.15	0.28	0.18
Al2O3	11.88	12.49	12.55	12.38	11.79	12.05	12.35	11.76	12.06	12.28	11.83
FeO	1.12	0.72	1.17	0.93	0.99	0.55	1.04	1.08	0.95	1.62	0.97
MgO	0.07	0.06	0.17	0.05	0.18	0.14	0.32	0.10	0.20	0.23	0.03
CaO	0.74	0.58	0.71	0.77	0.75	1.00	0.91	0.95	0.69	1.00	0.75
Na2O	3.75	3.15	3.59	3.71	3.87	3.66	3.70	3.74	3.53	4.35	3.58
K2O	3.97	4.73	4.07	3.97	4.20	3.81	3.74	3.42	4.27	3.26	4.17
Cl	0.14	0.14	0.14	0.12	0.11	0.10	0.14	0.15	0.13	0.12	0.15
Total	98.08	96.76	97.60	95.35	97.43	96.42	98.07	95.58	96.50	95.39	96.03

Normalised Data

	x	z	x	y	x	z	y	y	x	z	x	Mean
SiO2	77.81	77.15	76.93	76.81	77.40	77.69	77.13	77.60	77.24	75.74	77.45	77.18
TiO2	0.08	0.24	0.12	0.20	0.14	0.21	0.24	0.23	0.15	0.29	0.19	0.19
Al2O3	12.12	12.91	12.86	12.99	12.10	12.50	12.59	12.31	12.50	12.87	12.31	12.55
FeO	1.14	0.74	1.20	0.97	1.02	0.57	1.06	1.13	0.98	1.70	1.00	1.05
MgO	0.07	0.06	0.18	0.06	0.19	0.14	0.32	0.10	0.20	0.24	0.03	0.14
CaO	0.76	0.60	0.73	0.80	0.77	1.03	0.92	0.99	0.71	1.05	0.79	0.83
Na2O	3.82	3.26	3.67	3.89	3.97	3.80	3.77	3.91	3.66	4.56	3.73	3.82
K2O	4.05	4.89	4.17	4.17	4.31	3.95	3.82	3.58	4.43	3.42	4.34	4.10
Cl	0.14	0.15	0.15	0.12	0.12	0.10	0.15	0.16	0.13	0.13	0.16	0.14
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity coefficients

	KupeC	'KaukateaC	'PotakaD	'RewaE	'MangapipiC	'PakikihuraE	'Mangahou	T 5	T 10
All	0.883	0.857	0.872	0.833	0.839	0.806	0.762	0.906	0.918
X	0.902	0.800	0.900	0.783	0.804	0.836	0.762	0.942	0.907
Y	0.876	0.907	0.847	0.849	0.825	0.799	0.845	0.879	0.891
Z	0.855	0.874	0.847	0.820	0.810	0.782	0.814	0.866	0.877

	T 11	T 16	T 27	T 29	T 30	T 31	T 38	T 39	T 39x	T 39y
All	0.886	0.918	0.903	0.908	0.921	0.896	0.892			
X	0.858	0.943	0.883	0.939	0.949	0.938	0.942	0.929		
Y	0.891	0.883	0.911	0.879	0.884	0.871	0.853	0.947	0.883	
Z	0.875	0.888	0.884	0.892	0.888	0.878	0.851	0.943	0.883	0.959

' Normalised data from Pillans et al (1994).

Tephra: T 40

Description: pumice in shell conglomerate (Makuhou Shell Conglomerate)

Grid Reference: S22/092312

Microprobe Data

T40	1	2	3	4	5	6	7	8	9	10	11
SiO2	74.14	72.95	75.06	75.68	74.32	72.91	75.46	75.89	75.63	76.34	74.97
TiO2	0.15	0.21	0.17	0.15	0.15	0.10	0.15	0.19	0.13	0.13	0.17
Al2O3	12.06	12.79	11.98	11.93	11.74	11.74	11.97	12.01	12.06	11.88	11.88
FeO	0.90	1.93	0.91	1.17	1.14	0.86	1.00	0.90	1.17	1.25	1.25
MgO	0.09	0.20	1.13	0.12	0.15	0.11	0.19	0.18	0.12	0.06	0.13
CaO	0.71	0.96	0.79	0.82	0.94	0.79	0.85	0.73	1.01	0.94	0.93
Na2O	3.78	4.22	3.74	3.63	3.59	3.49	3.56	3.67	3.77	3.56	3.86
K2O	3.77	3.26	3.92	4.15	3.63	4.12	3.75	4.05	3.84	3.84	3.62
Cl	0.16	0.13	0.16	0.15	0.13	0.14	0.15	0.13	0.13	0.14	0.13
Total	95.75	96.63	97.86	97.81	95.77	94.24	97.08	97.74	97.85	98.13	96.91

Normalised Data

	x		x	y	y	x	y	x	y	y	y	Mean
SiO2	77.43	75.49	76.70	77.37	77.61	77.36	77.73	77.65	77.29	77.79	77.35	77.25
TiO2	0.15	0.22	0.17	0.16	0.15	0.11	0.15	0.19	0.13	0.13	0.17	0.16
Al2O3	12.59	13.23	12.24	12.20	12.25	12.45	12.33	12.29	12.33	12.10	12.26	12.39
FeO	0.94	2.00	0.93	1.19	1.19	0.91	1.03	0.92	1.20	1.27	1.29	1.17
MgO	0.09	0.21	1.15	0.13	0.15	0.11	0.20	0.18	0.13	0.07	0.13	0.23
CaO	0.74	0.99	0.81	0.84	0.98	0.84	0.88	0.75	1.03	0.96	0.96	0.89
Na2O	3.95	4.37	3.82	3.71	3.75	3.70	3.67	3.75	3.85	3.63	3.98	3.83
K2O	3.94	3.37	4.01	4.24	3.79	4.37	3.86	4.14	3.92	3.91	3.73	3.93
Cl	0.16	0.13	0.16	0.15	0.14	0.15	0.15	0.13	0.13	0.14	0.13	0.14
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Similarity Coefficients

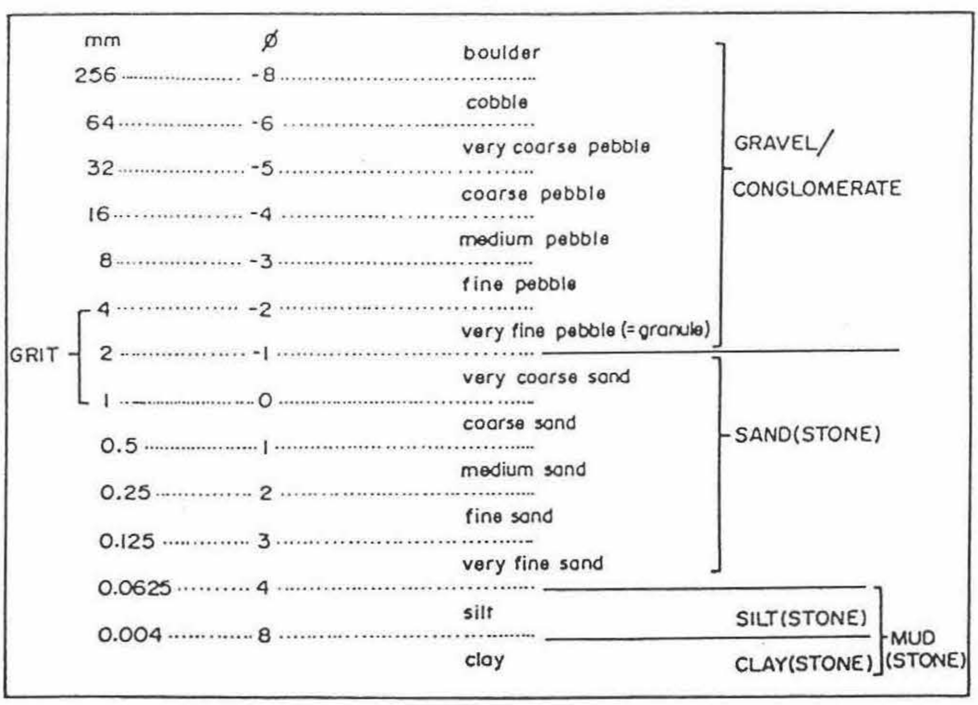
	KupeC	\`Kauk.C	\`PotakaD	\`RewaE	T 10	T 16	T 27	T 29	T 39x	T 39y	T 40	T 40x
All		0.837	0.849	0.820	0.911	0.871	0.959	0.864				
X	0.828	0.766	0.815	0.754	0.852	0.846	0.876	0.873	0.867	0.849	0.903	
Y	0.945	0.850	0.886	0.831	0.946	0.917	0.943	0.889	0.932	0.908	0.923	0.851

\` Normalised data from Pillans et al (1994).

Appendix B - Grain Size Analysis

Procedure

Sand samples were dried and sieved mostly through 1 mm - 0.063 mm (0 - 4.0 phi) sieves at 0.25 phi intervals. The Wentworth grade scale for grain size interpretation is included below. Each fraction was weighed and recorded in grams. For each sample, the weight % and cumulative weight % were calculated. A graph of phi values (0 - 4.0 phi) versus cumulative weight % was plotted for each sample to obtain phi values needed for statistical analysis. This data is included in this appendix, along with a statistical summary.



Wentworth Grade Scale from Andrews (1982).

Equations for Statistical Analysis

Median = phi 50 %

$$\textbf{Mean} = \frac{\text{phi } 16\,\% + \text{phi } 50\,\% + \text{phi } 84\,\%}{3}$$

$$\textbf{Standard Deviation} = \frac{\text{phi } 84\,\% - \text{phi } 16\,\%}{4} + \frac{\text{phi } 95\,\% - \text{phi } 5\,\%}{6.6}$$

Interpretation

Standard deviation and sorting :

Standard deviation values	Description
< 0.355	very well sorted
0.355 - 0.5	well sorted
0.5 - 0.71	moderately well sorted
0.71 - 1.0	moderately sorted
1.0 - 2.0	poorly sorted
2.0 - 4.0	very poorly sorted
> 4.0	extremely poorly sorted

Sample Number	Grid Reference	Dominant Grain Size		Cumulative Weight Percent (Phi values from graph)						
		mm	Phi	5 %	16 %	25 %	50 %	75 %	84 %	95 %
S 17	S23/027292	0.212 - 0.300	2.25 - 1.75	1.00	1.350	1.525	1.850	2.20	2.375	2.775
S 22	S22/062315	< 0.063 - 0.075	> 4.00 - 3.74	3.050	3.550	3.750	> 4.0	> 4.0	> 4.0	> 4.0
S 25	S22/072306	0.150 - 0.212	2.75 - 2.25	1.850	2.075	2.150	2.425	2.750	2.875	3.350
S 27	S22/069316	0.075 - 0.106	3.74 - 3.24	2.650	3.075	3.150	3.40	3.725	3.875	4.10
S 30	S22/092312	0.125 - 0.150	3.00 - 2.75	2.40	2.550	2.625	2.775	2.950	3.025	3.30
S 34	S22/118324	0.063 - < 0.063	< 4.00 - 4.00	3.30	3.650	3.750	> 4.0	> 4.0	> 4.0	> 4.0
S 35	S22/129322	0.355 - 0.500	1.50 - 1.00	0.625	0.80	0.925	1.125	1.40	1.650	2.70
S 36	S22/129322	0.125 - 0.180	2.75 - 2.47	2.050	2.225	2.375	2.650	2.925	3.00	3.40
S 41	S22/156354	0.125 - 0.150	3.00 - 2.75	2.10	2.40	2.525	2.70	2.925	3.075	3.450
S 43	S22/092321	0.075 - 0.090	3.74 - 3.47	1.40	2.30	2.825	3.50	> 4.0	> 4.0	> 4.0
S 46	S22/147366	1.00 - 2.00	0 - -0.25	< 0	< 0	< 0	1.60	2.050	2.250	3.050
S 51	S23/062301	0.075 - 0.106	3.74 - 3.24	2.350	2.950	3.125	3.40	3.675	3.850	4.050
S 54	S23/052287	0.106 - 0.125	3.24 - 3.00	2.20	2.60	2.750	3.025	3.325	3.50	> 4.0

Sample Number	Grid Reference	Statistical Summary		
		Median	Mean	Std. Dev.
S 17	S23/027292	1.85	1.86	0.52
S 22	S22/062315	--	--	--
S 25	S22/072306	2.42	2.46	0.43
S 27	S22/069316	3.40	3.45	0.42
S 30	S22/092312	2.775	2.78	0.25
S 34	S22/118324	--	--	--
S 35	S22/129322	1.125	1.19	0.53
S 36	S22/129322	2.65	1.6	0.40
S 41	S22/156354	2.70	2.70	0.37
S 43	S22/092321	--	--	--
S 46	S22/147366	--	--	--
S 51	S23/062301	3.40	3.40	0.48
S 54	S23/052287	--	--	--

Appendix C - Paleocurrent Data

Paleocurrent data from the Okehu Shell Grit at S22/129322

Compass Reading	A Dip and Direction (in degrees)	B Dip and Direction (in degrees)	True dip and Direction (in degrees)
1	1 @ 150	1 @ 43	2 @ 93
2	1 @ 166	12 @ 67	12 @ 80
3	6 @ 108	1 @ 230	8 @ 150
4	1 @ 125	1 @ 46	1 @ 82
5	3 @ 132	1 @ 29	4 @ 96
6	1 @ 302	2 @ 54	3 @ 2
7	3 @ 157	2 @ 72	3 @ 124
8	3 @ 145	1 @ 81	2 @ 140
9	18 @ 146	19 @ 70	17 @ 114
10	10 @ 165	9 @ 96	11 @ 132
11	3 @ 157	5 @ 98	5 @ 106
12	6 @ 180	3 @ 106	6 @ 153
13	4 @ 169	6 @ 282	9 @ 234
14	1 @ 160	1 @ 86	1 @ 117
15	6 @ 164	3 @ 78	6 @ 138
16	3 @ 187	1 @ 86	3 @ 149
17	9 @ 180	8 @ 74	9 @ 130
18	1 @ 276	1 @ 194	1 @ 254
19	8 @ 150	7 @ 64	10 @ 110
20	8 @ 161	6 @ 255	10 @ 202

Lower part of formation

21	11 @ 187	4 @ 105	12 @ 160
22	13 @ 187	15 @ 90	20 @ 133
23	3 @ 195	23 @ 100	23 @ 111
24	19 @ 15	15 @ 115	23 @ 58
25	11 @ 18	24 @ 114	25 @ 89
26	8 @ 18	12 @ 97	13 @ 73

Rose Diagram

Degrees	Upper part of formation	Lower part of formation	Combined Data
0 - 60	1	1	2
60 - 120	8	3	11
120 - 180	8	2	10
180 - 240	2	0	2
240 - 300	1	0	1
300 - 360	0	0	0

Paleocurrent data from the Potaka Pumice (Deepdem Conglomerate) member of the Kaimatira Pumice Sand at S22/090310 and several sites near to this location.

Compass Reading	A Dip and Direction (in degrees)	B Dip and Direction (in degrees)	True dip and Direction (in degrees)
	Potaka Pumice	**at S22/090310**	
1	4 @ 106	7 @ 201	8 @ 165
2	13 @ 100	23 @ 12	24 @ 36
3	2 @ 316	15 @ 217	15 @ 234
4	10 @ 115	2 @ 210	11 @ 131
5	1 @ 120	6 @ 21	6 @ 40
6	1 @ 297	13 @ 202	13 @ 214
7	10 @ 115	5 @ 30	11 @ 94
8	3 @ 295	5 @ 208	6 @ 244
9	1 @ 105	14 @ 16	14 @ 20
10	11 @ 130	13 @ 35	17 @ 78
11	4 @ 123	6 @ 230	9 @ 185
12	6 @ 104	21 @ 205	22 @ 182
13	11 @ 101	3 @ 210	13 @ 132
14	11 @ 310	29 @ 208	30 @ 234
15	15 @ 128	18 @ 23	24 @ 71
16	9 @ 106	6 @ 200	11 @ 140
17	11 @ 287	10 @ 17	14 @ 328
18	14 @ 76	6 @ 174	16 @ 104
19	12 @ 253	14 @ 166	17 @ 204
20	10 @ 309	5 @ 36	11 @ 332
21	2 @ 128	7 @ 225	7 @ 201
22	10 @ 120	16 @ 40	17 @ 62
23	16 @ 122	6 @ 38	16 @ 107

Potaka Pumice near S22/090310

24	16 @ 275	15 @ 354	19 @ 310
25	3 @ 285	3 @ 12	4 @ 323
26	16 @ 208	13 @ 178	19 @ 230
27	4 @ 90	3 @ 356	5 @ 54
28	2 @ 259	7 @ 355	7 @ 328
29	2 @ 256	8 @ 172	7 @ 182
30	10 @ 262	24 @ 359	25 @ 333
31	14 @ 77	25 @ 310	31 @ 3
32	4 @ 156	3 @ 111	4 @ 148
33	2 @ 76	24 @ 185	25 @ 163
34	21 @ 40	3 @ 341	22 @ 65
35	8 @ 188	23 @ 103	23 @ 114
36	12 @ 40	18 @ 322	19 @ 344
37	4 @ 52	17 @ 118	17 @ 129
38	5 @ 209	7 @ 143	7 @ 162
39	11 @ 223	15 @ 132	18 @ 166
40	15 @ 244	15 @ 356	23 @ 299
41	2 @ 238	15 @ 156	14 @ 157
42	24 @ 237	6 @ 165	24 @ 244
43	4 @ 54	20 @ 134	20 @ 134
44	9 @ 216	21 @ 154	21 @ 147
45	8 @ 223	3 @ 142	8 @ 211
46	11 @ 42	13 @ 140	17 @ 95
47	10 @ 216	18 @ 312	20 @ 280

Paleocurrent data from the Potaka Pumice (Deepdem Conglomerate) member of the Kaimatira Pumice Sand at S22/137318.

Compass Reading	A Dip and Direction (in degrees)	B Dip and Direction (in degrees)	True dip and Direction (in degrees)
1	3 @ 9	13 @ 100	14 @ 80
2	10 @ 6	3 @ 286	3 @ 298
3	10 @ 190	5 @ 288	11 @ 216
4	2 @ 356	2 @ 290	2 @ 317
5	3 @ 343	5 @ 279	5 @ 287
6	8 @ 173	11 @ 90	13 @ 120
7	5 @ 149	14 @ 68	14 @ 79
8	5 @ 155	11 @ 65	12 @ 88
9	10 @ 190	9 @ 65	19 @ 128
10	7 @ 195	8 @ 253	9 @ 235
11	23 @ 345	14 @ 265	24 @ 324
12	23 @ 149	25 @ 78	27 @ 117
13	18 @ 155	5 @ 76	18 @ 151
14	15 @ 148	5 @ 73	15 @ 142
15	4 @ 324	25 @ 55	25 @ 47
16	8 @ 144	9 @ 43	13 @ 90
17	17 @ 139	6 @ 55	17 @ 127
18	19 @ 320	9 @ 254	19 @ 318
19	8 @ 150	27 @ 238	17 @ 229
20	9 @ 129	26 @ 41	27 @ 54
21	5 @ 311	11 @ 244	11 @ 248
22	7@ 131	5 @ 44	8 @ 97
23	19 @ 314	7 @ 238	19 @ 308
24	21 @ 133	16 @ 53	23 @ 105
25	8 @ 305	6 @ 33	9 @ 340
26	26 @ 123	10 @ 35	26 @ 110

Rose Diagrams

Degrees	S22/090310	sites near to S22/090310	Combined Data	S22/137318
0 - 60	3	2	5	2
60 - 120	6	3	9	9
120 - 180	4	8	12	4
180 - 240	7	3	10	3
240 - 300	1	3	4	3
300 - 360	2	5	7	5

Paleocurrent data from the Kaikokopu Shell Grit at S22/072306

Compass Reading	A Dip and Direction (in degrees)	B Dip and Direction (in degrees)	True dip and Direction (in degrees)
1	9 @ 205	11 @ 136	11 @ 164
2	4 @ 35	9 @ 305	10 @ 326
3	11 @ 210	14 @ 145	15 @ 166
4	19 @ 190	12 @ 115	20 @ 173
5	25 @ 214	8 @ 138	25 @ 212
6	14 @ 203	25 @ 285	26 @ 268
7	5 @ 210	18 @ 286	18 @ 285
8	19 @ 219	30 @ 261	31 @ 284
9	9 @ 223	5 @ 317	11 @ 254
10	4 @ 229	6 @ 120	9 @ 169
11	4 @ 220	2 @ 126	4 @ 190
12	6 @ 208	20 @ 160	22 @ 131
13	18 @ 218	10 @ 144	18 @ 206
14	5 @ 219	10 @ 161	10 @ 160
15	5 @ 215	5 @ 314	7 @ 262
16	6 @ 206	1 @ 175	9 @ 258
17	8 @ 239	27 @ 167	27 @ 162
18	7 @ 282	1 @ 335	7 @ 256
19	9 @ 49	3 @ 345	8 @ 50
20	7 @ 242	9 @ 158	10 @ 196
21	2 @ 227	8 @ 150	8 @ 156
22	13 @ 221	4 @ 300	18 @ 232
23	4 @ 205	6 @ 154	6 @ 152
24	13 @ 22	2 @ 130	15 @ 49
25	11 @ 31	8 @ 134	15 @ 74

Rose Diagram

Degrees	S22/072306
0 - 60	2
60 - 120	1
120 - 180	9
180 - 240	5
240 - 300	7
300 - 360	1

Appendix D - Height (altimeter) Data

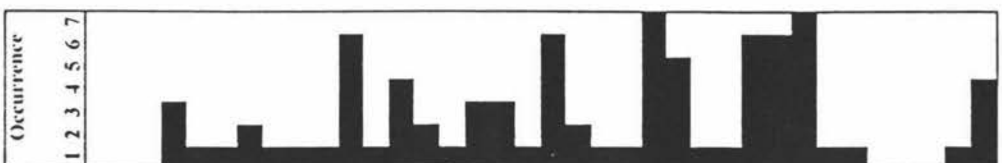
Grid Ref.	Formation/Contact	Height (asl)
S22/128341	Maxwells Group (lignite band)	234.5 m
S22/091362	Lower Okehu Siltstone	45.5 m
S22/091362	Lower Okehu Siltstone/Okehu Shell Grit	43.5 m
S22/129322	Lower Okehu Siltstone/Okehu Shell Grit	228.5 m
S22/095307	Upper Okehu Siltstone/Potaka Pumice (KPS)	97.5 m
S22/137318	Upper Okehu Siltstone/Potaka Pumice	257 m
S22/151355	Potaka Pumice (KPS)	261.5 m
S22/147366	Potaka Pumice (ashy member)	262 m
S22/069344	Kaimatira Pumice Sand/Makuhou Shell Conglomerate	85 m
S22/092312	Makuhou Shell Conglomerate	129 m
S22/077319	Lower Westmere Siltstone/Kaikokopu Shell Grit	107 m
S22/093314	Lower Westmere Siltstone/Kaikokopu Shell Grit	176.5 m
S22/095316	Lower Westmere Siltstone/Upper Westmere Siltstone	208 m
S22/089323	Lower Westmere Siltstone/Kaikokopu Shell Grit	166 m
S22/091317	Kaikokopu Shell Grit	171.5 m
S22/077319	Kaikokopu Shell Grit/Upper Westmere Siltstone	114 m
S22/069318	Kaikokopu Shell Grit/Upper Westmere Siltstone	79 m
S22/083316	Morgans Shellbed/Upper Westmere Siltstone	160.5 m
S22/092321	Morgans Shellbed/Upper Westmere Siltstone	201 m
S22/082320	Morgans Shellbed	159 m
S22/056323	Morgans Shellbed	50.5 m
S22/064314	Upper Westmere Siltstone/Kupe Formation	81.5 m
S22/051316	Upper Westmere Siltstone/Kupe Formation	32 m
S22/061311	Kupe Formation	95.75 m
S22/066315	Upper Kai-iwi Siltstone/Seafield Sand	127 m
S23/073302	Seafield Sand (streaky - bedded unit)	113 m
S23/082296	Seafield Sand (interbedded silt and sand unit)	147 m

S23/082296	Seafield Sand (mid-formation shellbeds)	149 m
S23/086294	Seafield Sand/Lower Castlecliff Shellbed	173 m
S23/086294	Lower Castlecliff Shellbed/Lower Castlecliff Siltstone	166 m
S23/056301	Lower Castlecliff Siltstone	105 m
S23/056301	Pinnacle Sand	110 m
S23/057295	Pinnacle Sand/Tainui Shellbed	120 m
S22/069316	Pinnacle Sand/Tainui Shellbed	151 m
S23/057295	Tainui Shellbed/Shakespeare Cliff Siltstone	122 m
S23/048287	Shakespeare Cliff Siltstone/Shakespeare Cliff Sand	99 m
S23/031298	Shakespeare Cliff Sand	39 m
S23/031309	Shakespeare Cliff Sand	63 m
S23/027294	Upper Castlecliff Shellbed/Karaka Siltstone	22 m

Appendix E - Macrofauna assemblages and occurrence from Type A1 and B Shellbeds in Turakina Valley

<u>Type A1 Shellbeds</u>: Table shows the number of samples out of 7 in which individual species occur (M.S.C. = Makuhou Shell Conglomerate; p = present).

Macrofossil Taxa	Kaikokopu Shell Grit				Kupe Formation		M.S.C
(Type A1 Shellbed)	f156	f157	f159	f160	f143	f151	f155
<u>Bivalvia</u>							
Anchomasa (Barnea) similis	p		p	p			
Anomia trigonopsis							p
Bassina yatei		p					
Carycorbula zelandica					p	p	
Cyclomactra tristis			p				
Dosinia zelandica					p		
Felaniella zelandica					p		
Glycymeris modesta	p	p	p	p	p		p
Limaria orientalis						p	
Maorimactra n. sp.	p	p	p	p			
Myadora striata					p	p	
Myadora subrostrata					p		
Nemocardium pulchellum			p	p		p	
Notocallista multistriata		p	p			p	
Nucula nitidula			p				
Paphies n. sp.	p	p	p	p	p		p
Paphies australis					p	p	
Paphies 'tuatua'						p	
Pleuromeris marshalli							p
Pleuromeris zealandica	p	p	p	p	p	p	p
Purpurocardia purpurorata	p	p			p	p	p
Serratina charlottae						p	
Spisula aequilatera					p		
Talochlamys gemmulata	p	p	p	p		p	p
Tawera spissa	p	p		p	p	p	p
Tiostrea chilensis lutaria	p	p	p	p	p	p	p
Tucetone laticostata							p
Zemysia zelandica						p	
<u>Gastropoda</u>							
Agatha georgiana			p				
Alcithoe arabica		p	p		p	p	



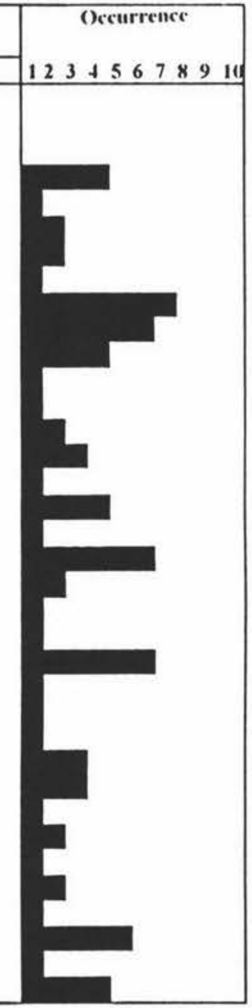
Macrofossil Taxa (Type A1 Shellbeds)	Kaikokopu Shell Grit				Kupe Formation		M.S.C	Occurrence
	f156	f157	f159	f160	f143	f151	f155	1 2 3 4 5 6 7
Ilcithoe fusus	p					p		
Imalda (Baryspira) australis		p	p					
Imalda (Baryspira) mucronata	p	p	p		p	p	p	
I (Gracilispira) novaezealandia	p	p	p	p	p	p	p	
Imphibola crenata				p				
Intimelatoma buchanani				p	p		p	
Intisolarium egenum					p	p		
Intizarfra ? pisanoides							p	
Ioteadrilla wanganuiensis			p	p			p	
Iustrofusus glans	p	p		p				
Iustromitra rubiginosa				p				
Bathytoma murdochi							p	
Buccinulum sp.					p		p	
Buccinulum caudatum			p					
Buccinulum linea			p	p				
Buccinulum vittatum	p							
Calliastroma nukumaruensis	p						p	
Calliastroma selectum				p				
Cirsotrema zelebori	p						p	
Cominella sp.					p			
Crepidula 'radiata'	p	p					p	
Diloma subrostrata		p						
Globisinum drewi			p					
Leucotina ambigua	p	p	p	p	p	p		
Liracraea ? odhneri				p				
Maoricolpus roseus	p	p	p	p	p	p	p	
Michrelenchus ? sanguineus						p		
Murexsul octogonus			p					
Neoguraleus sp.	p	p	p	p	p			
Odostomia sp.					p			
Paracomitas protransenna							p	
Paratrophon sp.	p	p	p					
Pelicaria vermis	p	p	p			p	p	
Penion sp.	p	p	p			p	p	
Pervicacia tristis		p	p	p			p	
Phenatoma novaezealandiae		p						
Phenatoma rosea	p							
Poirieria zelandica	p	p						
proxiuber australe		p	p			p		

Macrofossil Taxa	Kaikokopu Shell Grit				Kupe	Formation	M.S.C	Occurrence
(Type A1 Shellbeds)	f156	f157	f159	f160	f143	f151	f155	1 2 3 4 5 6 7
Seila sp.						p	p	
Semicassis pyrum			p					
Sigapatella novaezelandiae						p		
Stiracolpus sp.						p	p	
Stiracolpus aff. symmetricus	p		p	p	p			
Stiracolpus ? murdochi		p						
Struthiolaria papulosa	p		p	p				
Tanea zelandica	p		p				p	
Trochus tiaratus		p	p	p	p	p		
Uberella sp.					p			
Xymene ambiguus	p	p	p				p	
Xymene bonnetti			p					
Xymene expansus	p	p	p	p			p	
Xymene plebeius					p	p		
Xymene pusillus				p	p		p	
Zafra sp.	p				p		p	
Zeacolpus vittatus	p	p	p				p	
Zeacumantus lutulentus					p			
Zegalerus tenuis			p	p	p	p	p	
Zemitrella sp.			p		p		p	
Zethalia zelandica		p	p	p	p	p	p	
Scaphopoda								
Antalis nana	p	p	p	p	p		p	
Brachiopoda								
Waltonia inconspicua						p	p	
Bryozoa					p	p	p	

<u>Type B Shellbeds</u>: Table shows the number of samples out of 10 in which individual species occur (U.C.Sb. = Upper Castlelcliff Shellbed; p = present).

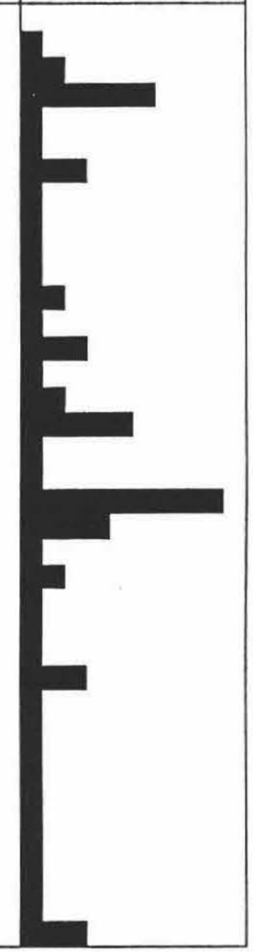
Macrofossil Taxa	Morgans Shellbed			Howie Shellbed	Lower Castlecliff Shelllbed		Tainui Shellbed			U.C.Sb.
(Type B Shellbed)	f148	f149	f154b	f90	f85	f89	f84a	f84b	f146	f83a
<u>Bivalvia</u>										
Atrina pectinata zelandica	p	p	p			p				
Austrovenus crassitesta									p	
Austrovenus stutchburyi									p	p
Barbatia novaezelandiae					p		p			
Cardita aoteana					p					
Carycorbula zelandica		p	p	p	p	p	p	p		
Chlamys gemmulata	p				p		p	p	p	p
Chlamys zelandiae	p	p			p					p
Cyclomactra tristis			p							
Divariella huttoiona										p
Dosinia (Phacosoma) mauriana							p		p	
Dosinia (Phacosoma) subrosea							p	p		p
Dosinia (Kereia) greyi					p					
Dosinia zelandica	p	p	p		p					
Elliptolellina urinatonia					p					
Felaniella zelandica	p	p			p		p	p		p
Gari hodgei					p					p
Gari stangeri						p				
Glycymeris sp.				p						
Glycymeris modesta		p	p		p		p	p	p	
Gonimytrea cincinna				p						
Hiatella aretica					p					
Kellia cycladiformis		p								
Leptomya retiaria		p	p				p			
Limatula maoria				p			p			p
Limaria orientalis					p					
Mesophylum convexum					p		p			
Modiolus arealatus									p	
Myadora boltoni					p	p				
Myadora novaezelandiae					p					
Myadora striata			p	p	p	p				p
Myadora subrostrata		p								
Nemocardium pulchellum		p	p		p	p				

Occurrence



Macrofossil Taxa	Morgans Shellbed			Howie Shellbed	Lower Castlecliff Shellbed		Tainui Shellbed			U.C.Sb.
(Type B Shellbeds)	f148	f149	f154b	f90	f85	f89	f84a	f84b	f146	f83a
Notocallista multistriata		p	p		p	p				
Nucula nitidula					p		p	p		p
Oxyperas elongata	p								p	
Panopea wanganuica/smithae						p				
Paphies donacina									p	
Paphies 'tuatua'			p							
Pecten sp.	p	p			p		p	p	p	
Pleuromeris marshalli					p					p
Pleuromeris zealandica	p	p	p	p	p	p	p	p		p
Purpurocardia purpurata	p	p	p	p	p		p	p	p	p
Raditapes targillierti										p
Scalpomactra scalpellum		p			p		p	p		p
Spisula aequilatera									p	
Talochlamys gemmulata			p	p		p				
Talochlamys zelandiae			p							
Tawera spissa	p	p	p	p	p	p	p	p	p	p
Thracia vegrandis		p								
Tiostrea charlottae									p	
Tiostrea chilensis lutaria	p	p	p		p	p	p	p	p	p
Tucetona laticostata					p		p	p	p	
Zemysia zelandica			p	p						
Zemysina globus				p						
Gastropoda										
Aeneator marshalli			p							
Agatha georgina					p					
Alcithoe sp.		p								
Alcithoe arabica	p		p				p			
Alcithoe fusus			p							
Alcithoe (Leporemax) sp.										p
Amalda sp.		p			p					
Amalda (Baryspira) mucronata			p	p	p		p	p	p	p
A. (Gracilisprira) novaezelandiae	p	p	p			p	p	p		
Antimelatoma buchanani		p	p		p		p	p		
Antisolarium egenum		p		p	p	p		p		p
Austrodrillia wanganuiensis										

Macrofossil Taxa (Type B Shellbeds)	Morgans Shellbed			Howie Shellbed	Lower Castlecliff Shellbed		Tainui Shellbed			U.C.Sb.	Occurrence
	f148	f149	f154b	f90	f85	f89	f84a	f84b	f146	f83a	1 2 3 4 5 6 7 8 9 10
Astrea heliotropium							p				
Ataxocerithium huttoni				p	p						
Austrofusus glans	p			p		p	p	p		p	
Austromitri sp.										p	
Austromitra planata							p				
Buccinulum linea				p	p		p				
Cabestana tabulata				p							
Callistoma sp.					p						
Callistoma ? pellucida				p							
Cominella elegantula							p				
Crepidula costata					p					p	
Dolicrassea vesca					p						
Duplicaria tristis							p	p		p	
Emarginata striatula					p						
Glaphyrina caudata				p			p				
Leucotina ambigua		p	p	p	p	p					
Liracraea odhneri			p								
Liratilia conquisita					p						
Maoricolpus roseus	p	p	p	p	p	p	p		p	p	
Michrelenchus sp.		p			p		p	p			
Michrelenchus rufozona										p	
Michrelenchus ? sanguineus			p	p							
Microvoluta biconica				p							
Microvoluta marginata								p			
Naticidae sp.		p									
Neogurleus sp.		p			p	p					
Notoacmea sp.										p	
Nozeba emarginata					p						
Patelloida corticata			p								
Pelicaria vermis		p									
Penion cuvierianus							p				
Phenotoma rosea					p						
Pisinna sp.					p						
Poirieria zelandica				p							
Retusa oruaensis					p						
Seila sp.			p	p	p						



Macrofossil Taxa	Morgans Shellbed			Howie Shellbed	Lower Castlecliff Shellbed		Tainui Shellbed			U.C.Sb.	Occurrence
(Type B Shellbeds)	f148	f149	f154b	f90	f85	f89	f84a	f84b	f146	f83a	1 2 3 4 5 6 7 8 9 10
Sigapatella novaezelandiae	p	p	p		p		p	p		p	
Stiracolpus sp.			p				p			p	
Stiracolpus aff. symmetricus	p	p				p					
Stiracolpus cf. blacki					p			p			
Stiracolpus ? delli				p							
Stiracolpus ? waikoperoensis						p					
Struthiolaria papulosa	p			p		p			p		
Tanea zelandica				p	p					p	
Tomopleura subalbula					p						
Trochus tiaratus	p	p	p	p	p	p					
Trochus (Thorista) viridis					p						
Tugali pliocenica							p				
Uberella sp.			p								
Xymene ambiguus								p			
Xymene bonnetti				p		p					
Xymene plebeius		p			p	p			p	p	
Xymene pusillus		p	p		p			p		p	
Xymene traversi					p		p				
Zeacolpus vittatus			p	p	p		p		p		
Zegalerus tenuis		p	p		p	p		p		p	
Zemitrella choava										p	
Zemitrella sulcata							p				
Zethalia zelandica								p		p	
Scaphopoda											
Antalis nana		p	p		p	p		p			
Brachiopoda											
Magasella sanguinea	p										
Neothyris sp.							p		p		
Waltonia inconspicua	p	p	p		p	p	p				

Macrofossil Taxa	Morgans Shellbed			Howie Shellbed	Lower Castlecliff Shellbed		Tainui Shellbed			U.C.Sb.	Occurrence
(Type B Shellbeds)	f148	f149	f154b	f90	f85	f89	f84a	f84b	f146	f83a	1 2 3 4 5 6 7 8 9 10
Echinoidea											
Psuedechinus sp.			p								
Fellaster zelandiae					p						
Bryozoa											
stick, button and branch			p	p	p	p	p	p		p	
Coelenterata, Scleractinia											
Flabellum rubrum									p		
Crustacea											
Callianassid		p									