FIELD TRIP 7

Wanganui: Sea Level Cycles, Tephras and Terraces in the Late Cenozoic

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Figure 1. Bluff on the south side of Okehu Stream contains spectacular exposures through basin cycles 33 to 35. The TST of cycle 34 (Kaimatira Pumice Sand) is overthickened by the rapid introduction of volcaniclastic sediment associated with the Potaka Tephra eruption (equivalent to Unit E ignimbrite) from the Taupo Volcanic Zone c. 1 Ma (Photo: Tim Naish).

Programme

Overall Objective:

Although Wanganui basin sediments have been studied since 1940's, this field-trip will emphasize the role of high-resolution integrated chronology (tephra, biostratigraphy, and paleomagnetism) to provide a framework for understanding Plio-Pleistocene sea-level and climate reconstruction. Key references are given at the end of this field guide.

26 November

Depart Wellington - 5 pm

- Dinner on road (recommended Manor Café 3km So of Bulls)
- Accommodation: Whanganui River Top 10 Holiday Park (460 Somme Parade)

27 November

DAY 1 Objective:

We will start the day by looking at outcropping shallow-marine sediment of the Nukumaruan Group beneath the Brunswick Marine Terrace (c. 310 ka; Stage 9). We will then proceed to Rangitatau East Road where we will examine a loess-paleosol sequence with intercalated tephra and dune sand on one of the oldest uplifted marine terrace remnants in the Wanganui area. We will then proceed to the coast to look at outcropping shallow-marine sequence stratigraphy at Ototoka Stream then at Kai-iwi Beach.

Morning. Depart 8 – 8:30 am (breakfast and lunch provided)

- **STOP 1**: Vinegar Hill Tephra (c. 1.75 Ma; Cycle 19) within Maxwell Group exposed at Brunswick Road (R22/779503) (Brent & Brad)
- **STOP 2**: Interbedded loess and paleosol layers on a pre-Marorau Terrace (c. 680 ka; Stage 17) at Rangitatau East Road (R22/767594). Rangitawa Tephra (350 ka) is exposed within Loess L10 (Brent & Brad).

Afternoon.

- **STOP 3**: Butlers Shell Conglomerate unconformably overlying Maxwell Group (Mangahou Siltstone) at Ototoka Stream (R22/669472) (Gavin & Alan) and type section of the c. 1.75 Ma Ototoka Tephra (R22/674470) (Brent & Brad)
- **STOP 4**: Castlecliffian coastal stratigraphy at Kai-iwi (Gavin & Alan)
- **BBQ** at Holiday Park

28 November

DAY 2 Objective:

As we travel from Wanganui to the Rangitikei we will look at a number of sections (**STOPS 5, 6 & 7**) that expose important rhyolitic tephra marker beds that have been emplaced by a variety of primary and secondary processes. Once in the Rangitikei, we will look at massive siliciclastic sediments (outer shelf) of Mangaweka Mudstone (**STOP 8**) with interbedded Eagle Hill and Kowhai Tephras (c. 2.88 Ma). At **STOP 9,** a jet boat will take us to excellent exposures on the Rangitikei River, including the Hautawan shell bed which contains the oldest occurrence of the Sub-Antarctic bivalve *Zygochlamys delicatula* in North Island sedimentary basins. In New Zealand, the Plio-Pleistocene boundary was initially recognised at the base of the Nukumaruan Stage which coincided with this first incoming of *Zygochlamys delicatula*. However, we now know that the base of the Nukumaruan Stage has an age of c. 2.5 Ma (Naish et al. 1998). Our last stop of the fieldtrip (**STOP 10**) will be to view the impressive array of Rangitikei fluvial terraces from the Stormy Point Lookout.

Morning. Depart 8-8:30 am (breakfast and lunch provided)

- **STOP 5**: Fordell Ash section. Here the rhyolitic Fordell tephra is exposed within terrestrial lignite above marine sediments deposited after the cutting of the Braemore Marine Terrace c. 340 ka (OI substage 9c) (Brent & Brad).
- Turakina Valley to view different modes of silicic tephra emplacement within Wanganui Basin. Pakihikura (**STOP 6**) and Ototoka Tephra (**STOP 7**) (Brent & Brad)
- **STOP 8:** Mangaweka Mudstone & interbedded tephras (Brent & Kyle)

Afternoon.

- **STOP 9:** Jet-boat on the Rangitikei River at Ohingaiti to look at Late Pliocene shelf deposits MIS 88-100 along Rangitikei (several 10-15 min rides from Ohingaiti to outcrops) (Alan & Kyle)
- **STOP 10:** Stormy Point – Impressive view of Rangitikei fluvial terraces (Brad).

Arrive back in Wellington c. 5 pm.

Figure 2. Location of field trip stops.

Background information (*adapted from* Abbott et al. 2005, Naish et al. 2004, Saul et al. 1999)

Introduction

This two-day fieldtrip will examine Plio-Pleistocene age sediments and geomorphology of the Wanganui Basin. This region is unique in the world for the completeness and clarity of the sea level record preserved in both sedimentary cycles and marine terraces and the presence of numerous tephra suitable for dating.

To date fifty-eight Pliocene-Pleistocene sedimentary sequences, representing oxygen isotope stages 5 through to MG 6 (Abbott & Carter 1994; Journeaux et al. 1996; Naish & Kamp 1997; Naish et al. 1998; Saul et al. 1999; Naish et al., 2005; Abbott et al., 2005) have been recognised in spectacular outcrops along the south Taranaki-Wanganui coastline (see **Figure 3**). An overlapping and partly younger record of interglacial isotope stages 17–3 (0.68–0.04 Ma) is represented by a flight of 13 marine terraces that extend up to 20 km inland and up to 400-m above present sea level along the Wanganui coast (Pillans 1983, 1990).

The major sedimentary facies represented within the basin fill were deposited in a range of coastal plain, shoreface, and shelf marine environments during the late rise, highstand, and falling part of each glacio-eustatic cycle; i.e., the facies mostly represent interglacial oxygen isotope stages. In general, glacial stages are represented only by the surfaces of marine planation and bioerosion that mark the sequence boundaries at the base ofeach cyclothem. Marine ravinement and in situ boring pholad bivalves have removed all traces of nonmarine conditions at most such boundaries, apart from the rare preservation of subaerial surfaces (including soils) at some cycle boundaries near the inland edge of the basin (Abbott, 1992).

Broad-scale, sequence stacking patterns and sequence architecture also reflect tectonic influences associated with plate boundary processes during the evolution of the western North Island continental margin.

During the last ~10 years this margin has gained a reputation as the world's most complete outcrop exposure of a late Neogene (3.4-1.6 Ma) shallow-marine, siliciclastic depositional system (summarised in Volume 35 of the *Journal of the Royal Society of New Zealand*, 2005). Outcrop analogues of this exceptional quality are rare, as most late Neogene shelf margins underlie flooded continental shelves (e.g. Gulf of Mexico).

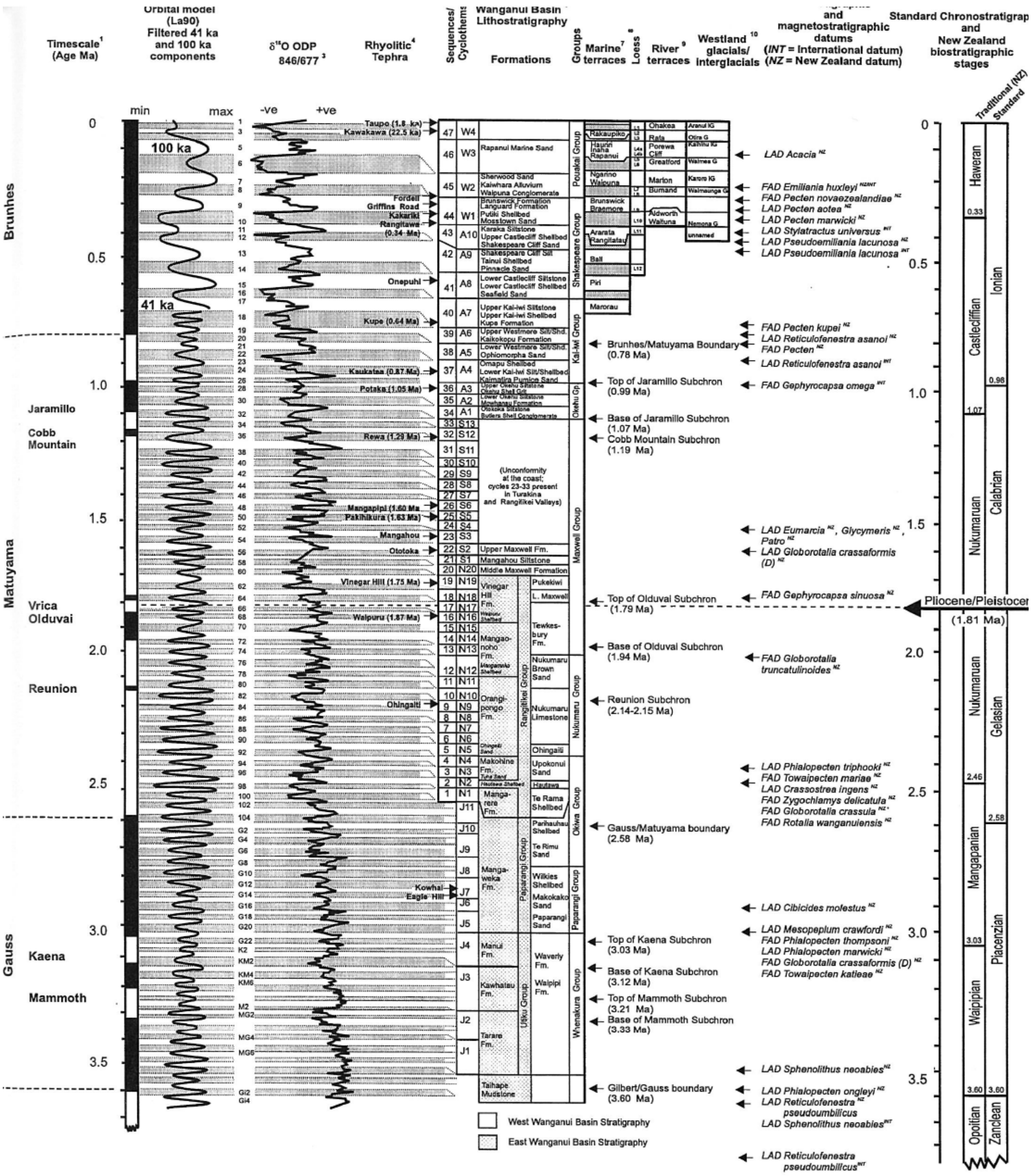

Figure 3. Integrated geochronology and stratigraphy of the Wanganui Basin (*from* Naish et al., 1998).

The sequence stratigraphic model

The Wanganui Basin fill is characterised by sedimentary cycles (depositional sequences) that generally range between a few to a few tens of metres in thickness, and their origin is attributed to glacial eustacy. A depositional sequence is defined as a package of genetically related strata, **bounded by unconformities** or their correlative conformities, that represents deposition during one complete cycle of relative sea-level change. The relative position of sea level within a depositional cycle is determined through **sedimentary facies analysis and macrofossil assemblages (shellbeds)**.

Naish and Kamp (1997) and Kondo et al. (1998), after Kidwell (1991), have recognised onlap, backlap, downlap, and flooding surface shellbeds. These shellbeds are associated, respectively, with the transgressive surface of erosion (TSE), a local flooding surface, the downlap surface, and paracycle-bounding marine flooding surfaces. In offshore settings, where the downlap surface converges with the sequence boundary, elements of both onlap and downlap shellbeds may become superposed. For such cases the term compound shellbed is useful. Abbott and Carter (1994) distinguished type A shellbeds within the transgressive systems tract (reworked shallow water species, often cross-bedded); and type B shellbeds (offshore shelf species, preserved in or near situ), which straddle the junction between the transgressive and highstand systems tracts, leading to the term midcycle shellbed.

Tables 1 and 2 summarise the sequence stratigraphic and shellbed nomenclature used on this trip, and its relationship to other shellbed schemes. While the shellbeds are given interpretative names, the shellbed types are recognised on the basis of distinctive physical characteristics (composition, sedimentary structures, and stratal relationships) observed in outcrop. Generic conceptual models of sequence architecture are shown **Figure 4**. In stratigraphic order, the important sediment-bounding surfaces are the lower sequence boundary (LSB), the transgressive surface of erosion (TSE), the local flooding surface (LFS), the downlap surface (DLS), the forced regressive downlap surface (FDS) and the upper sequence boundary (USB). Sequence boundaries often coincide with TSEs, and are sharply planed surfaces of marine erosion; when on siltstone the boundaries are often penetrated by pholad borings with shells sometimes preserved in borings; when on sandy substrate, the boundaries are often penetrated by *Ophiomorpha* and other burrows. Each sequence boundary is overlain by shallow marine, transgressive systems tract sands or by a transgressive shell lag or reworked onlap shellbed. Local flooding surfaces are either sharp, burrowed surfaces or rapidly gradational contacts. They represent levels in sequences where rapid deepening and shoreline transgression occurred. The uppermost, or single local flooding surface, is often marked by an overlying backlap shellbed (mid-cycle shellbed of Abbott and Carter, 1994) comprising relatively offshore, deep water fauna. The top of this backlap shellbed is marked by a downlap surface (DLS), a rapidly gradational contact with siltstone of the overlying highstand systems tract. A downlap shellbed may occur immediately above the DLS within the distal, basinward portion of progradational siliciclastic sediments of the highstand systems tract. The lower bounding surface of the RST, the forced regressive downlap surface (FRD), is abruptly gradational and marks a rapid upward shoaling. However, where this surface is erosional it is often overlain by a regressive shell lag and is referred to as the regressive surface of erosion (RSE; Plint, 1988). The upper-bounding surface of the RST is the sequence boundary, a subaerial unconformity that maybe marked by, a paleosol, a surface marking channel evulsion, fluvial channel incision or delta abandonment, and which passes into a correlative submarine conformity seaward of the lowstand shoreline, where it marks the base of the lowstand systems tract (LST).

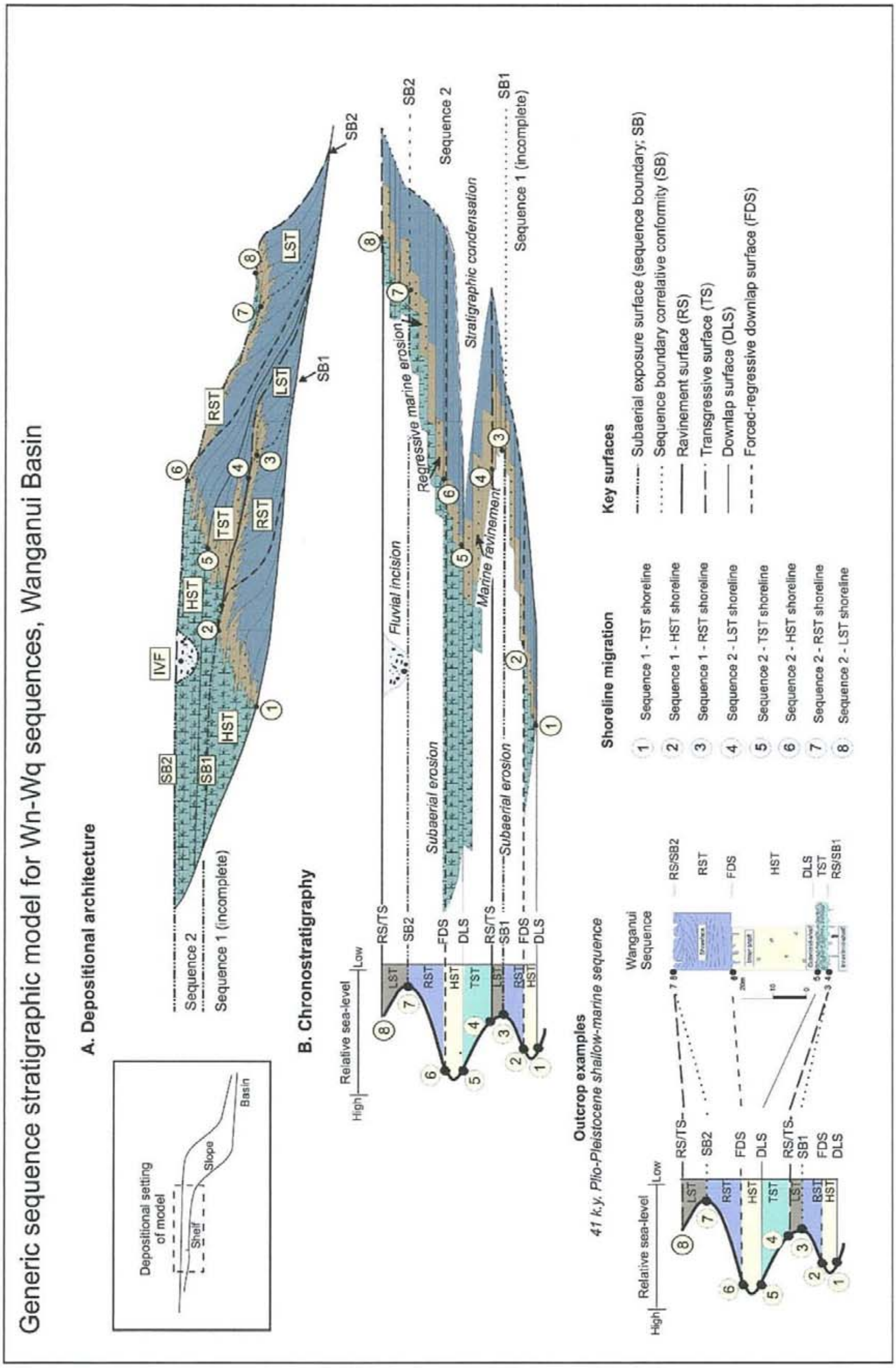

Figure 4. Generic sequence stratigraphic model for Wanganui Basin sediments.

Architecture of a generic 5th or 6th order sequence

Traditional facies and biofacies analysis is the basis of the interpretation of the depositional paleoenvironments of the Wanganui sequences. The recognition of vertically-stacked cyclical facies successions bounded by sharp erosion surfaces, that mark prominent lithological dislocations has allowed the Wanganui basin-fill to be readily subdivided into sequences (e.g. Abbott and Carter, 1994; Naish and Kamp, 1997a; Kamp and McIntyre, 1998). Typically the following architectural elements occur in ascending stratigraphic order:

1. A basal sequence boundary consisting of an unconformity, or its correlative conformity, which is coincident with the transgressive surface of erosion (TSE), or a subaerial unconformity marked by a paleosol, abrupt facies transition to non-marine sediments, or fluvial incision. In the latter case a lowstand systems tract (LST) comprising a succession of non-marine lacustrine, overbank, swamp and/or fluvial sediments may occur between the sequence boundary and the TSE.
2. Either (i) a thick (5-30 m) transgressive systems tract (TST) with a shallow-water reworked shell-bed at the base, overlain by inner-shelf sandstone and by a condensed shell-bed, or (ii) a thin transgressive systems tract « 2 m), corresponding mainly to a shallow-water condensed shell-bed.
3. A flooding surface, across which rapid deepening occurs, in most cyclothems located at the base of a mid-cycle condensed shell-bed with an offshore fauna.
4. A downlap surface (DLS).
5. A highstand systems tract (HST) (10-20 m) comprising an aggradational interval of shelf siltstone.
6. Commonly, a regressive systems tract (RST) (10-60 m), which overlies a forced regressive downlap surface (FDS), or where erosion has occurred a regressive surface of erosion (RSE). The RST commences with a gradational inner shelf to shoreface facies transition (facies SIS4), and passes up into a strongly progradational shoreline facies assemblage.

Table 1. Key of sequence stratigraphic terms

Unconformities and Depositional Surfaces	
SB	Sequence boundary
TSE RS	Transgressive surface of erosion =Ravinement surface
CC	Correlative conformity
DLS	Downlap surface
TS	Transgressive surface
LFS	Local flooding surface
MFS	Maximum flooding surface
FDS	Forced regressive downlap surface
RSE	Regressive surface of erosion
SU	Subaerial unconformity
Systems Tracts	
LST	Lowstand systems tract
TST	Transgressive systems tract
HST	Highstand systems tract
RST	Regressive systems tract
FRST	Forced regressive systems tract
Condensed intervals within systems tracts	
OS	Onlap shellbed
BS	Backlap shellbed
DS	Downlap shellbed
TS	Toplap shellbed
MCS	Mid-cycle shellbed

Table 2. Comparison of shellbed nomenclature of cyclothemic marine strata

Stratal relationship	Naish & Kamp (1997a) (genetic)	Abbott and Carter (1994) (descriptive/genetic)	Kidwell (1986) (descriptive)	Kidwell (1991) (genetic)
TST, HST, FRST; directly above local marine flooding surfaces	Marine flooding surface shellbed	Type B and/or Type A2 shellbed	Type 3	Condensation in the context of onlap
Base of HST directly above DLS	Downlap shellbed	Upper part of mid-cycle or Type B shellbed	Type 3	Condensation in the context of downlap
Top of TST; capped by downlap surface	Backlap shellbed	Lower part of mid-cycle or Type B shellbed	Type 1	Condensation in the context of backlap
Directly above correlative conformity	Onlap(2) shellbed		Type 3 & 4	Condensation in the context of onlap
Directly above the TSE	Onlap(1) shellbed	Type A shellbed	Type 4	Condensation in the context of onlap

Characteristic "stacking patterns" or motifs vary across the basin depending on the position of the paleoshoreline and sediment supply. In the Wanganui basin, Saul *et al.* (1999) recognised 7 sequence motifs characteristic of different paleogeographic settings (see **Figures 5 & 6**)

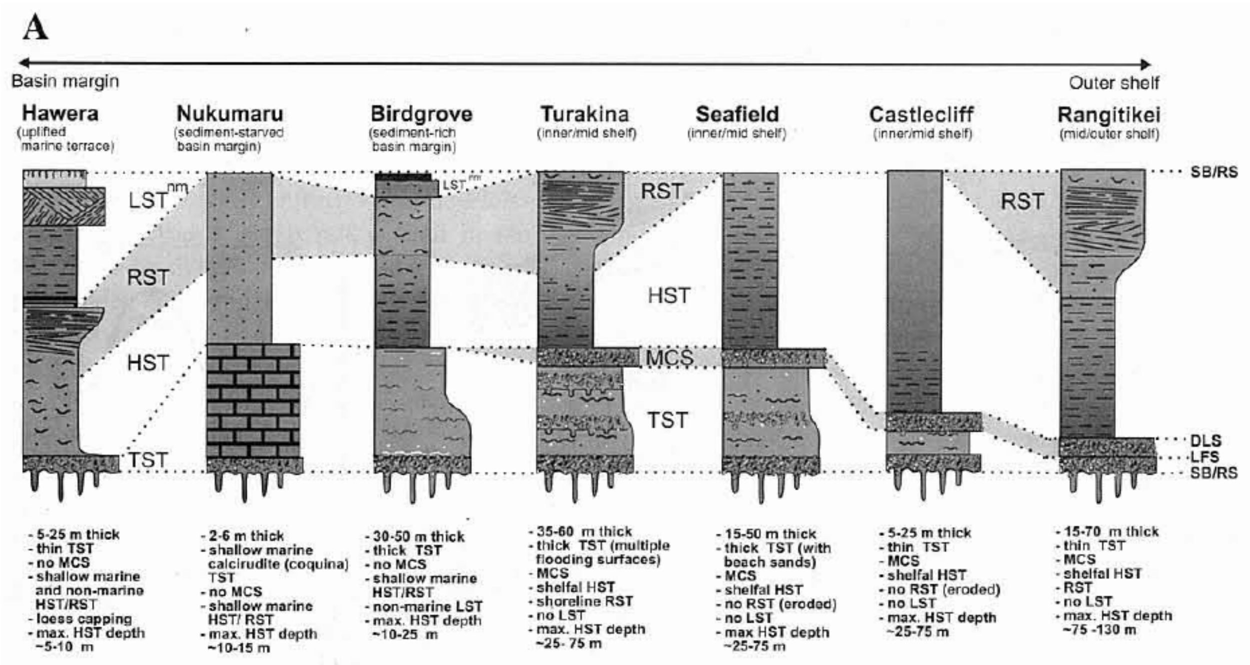

Figure 5. Summary diagrams of the seven major sequence motifs represented among Wanganui basin cyclothems. Note that the motifs are based upon observed lithologies, shell beds, and the physical surfaces that separate them.

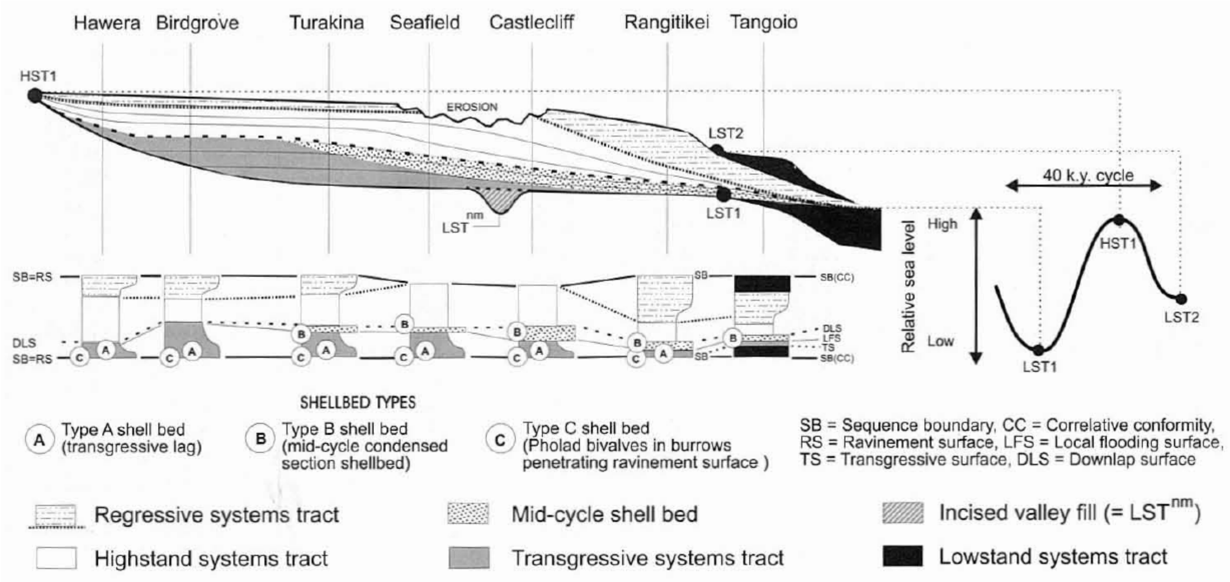

Figure 6. Wanganui and Tangoio cyclothem motifs depicted in relation to their paleogeographic position on the shelf, and their position with respect to sea-level highstand or lowstand. Key surfaces, shell beds, and systems tracts are indicated as appropriate.

Sedimentary Structures

The Wanganui sequences are characterized by a mosaic of shoreline to inner-shelf siliciclastic environments. These include estuaries (mud-rich) and beaches (sand-rich), which commonly pass offshore into normally graded (sand-rich to mud-rich) shore-connected sediment wedges on the inner-shelf (Abbott and Carter, 1994). Although sandy and gravelly facies mark cycles, the overall system is dominated by silts and muds from the offshore environments. Sedimentary structures and lithologies common to Wanganui sequences are shown in **Figure 7**.

Large-scale trough crossbedding in shell gravel indicates three-dimensional dune bedforms produced by strong unidirectional currents. The presence of such bedforms, with thicknesses of up to 1 m, implies the influence of strong tidal and/or storm-driven currents. Cross-bedding interlaminated with mud drapes is a sedimentary structure most commonly associated with tide-dominated environments, characterized by periods of alternating strong (cross-bedded, sand/silt/gravel deposition) and slack (drape, fine-silt and clay deposition) currents (Abbott and Carter, 1994). In high-energy, sandy shoreface environments, small-scale trough cross-stratification is commonly produced by longshore currents on open beaches. Commonly in sandy shorefaces, infaunal bivalve communities were reworked and concentrated into shell lags by storm waves or migrating rip channels (Abbott and Carter, 1994).

Seaward toward the transition into offshore muds, bioturbation becomes more pervasive and sediment texture becomes finer. Facies in these depositional environments are characterized by an intercalation of sand and mud. Such lithologies have been termed 'heterolithc' in the Wanganui sequence stratigraphy literature. In a muddy, inner-shelf environment, heterolithic alternation may result from fluctuating energy conditions resulting from storm-dominated, tide-dominated, or delta-front currents. Such heterolithic alternation could be confused with tidal-flat and estuarine environments. However, several features prominent in tidal-flat and estuarine features are missing from these inner-shelf environments (Abbott, 1998). First, there is no evidence of subtidal or intertidal channel facies. Second, fluvial and supratidal-flat facies (including peat, plant rootlets,and desiccation structures) are also absent despite their relatively high preservation potential. And third, the abundance of estuarine fossils are almost never observed *in situ* in these heterolithic associations (Abbott, 1998).

In the inner-shelf environments, which dominate the Wanganui sequences, the most common sedimentary structures are parallel and ripple lamination in a muddy lithology. Flaser bedding is a type of ripple lamination in which thin streaks of mud occur between sets of cross-laminated sandy or silty sediment (see **Figure 7**). Mud is concentrated mainly in the ripple troughs but may also partly cover the crests. Flaser bedding suggests deposition under fluctuating hydraulic conditions. Periods of current activity, when traction transport and deposition of rippled sand take place, alternate with periods of quiescence, when mud is deposited. Repeated episodes of current activity result in erosion of previously deposited ripple crests, allowing new rippled sand to bury and preserve rippled beds with mud flasers in the troughs (ReIneck and Singh. 1980). Lenticular bedding is a structure formed by interbedded mud and ripple crosslaminated sand in which the ripples or sand lenses are discontinuous and isolated in both a vertical and a horizontal direction (see **Figure 7**). Reineck and Singh (1980) suggest that flaser bedding is produced in environments in which conditions for deposition and preservation of sand are more favourable than for mud, but that lenticular bedding is produced in environments in which conditions favour deposition and preservation of mud over sand.

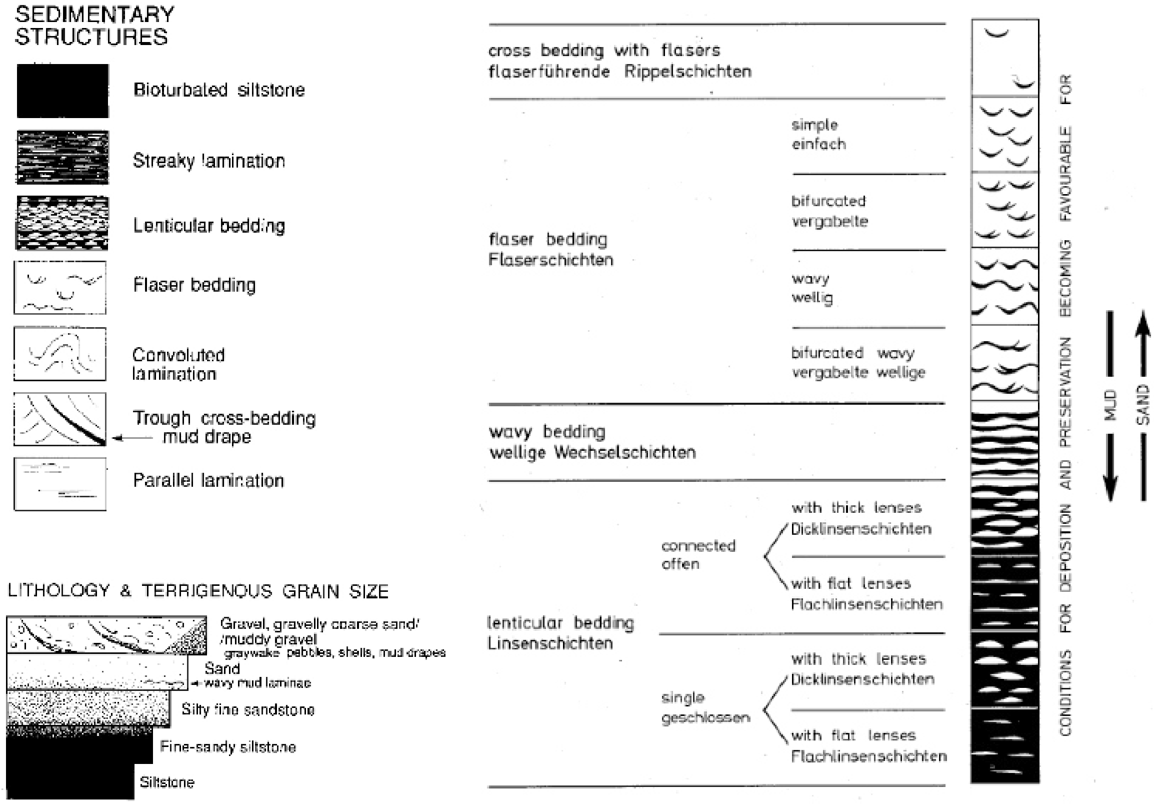

Figure 7. Common sedimentary structures and grain sizes seen in Wanganui sediments (modified from Abbott, 1998). Classification scheme of flaser and lenticular bedding (Black = mud; White = sand; modified from Reineck and Singh, 1975).

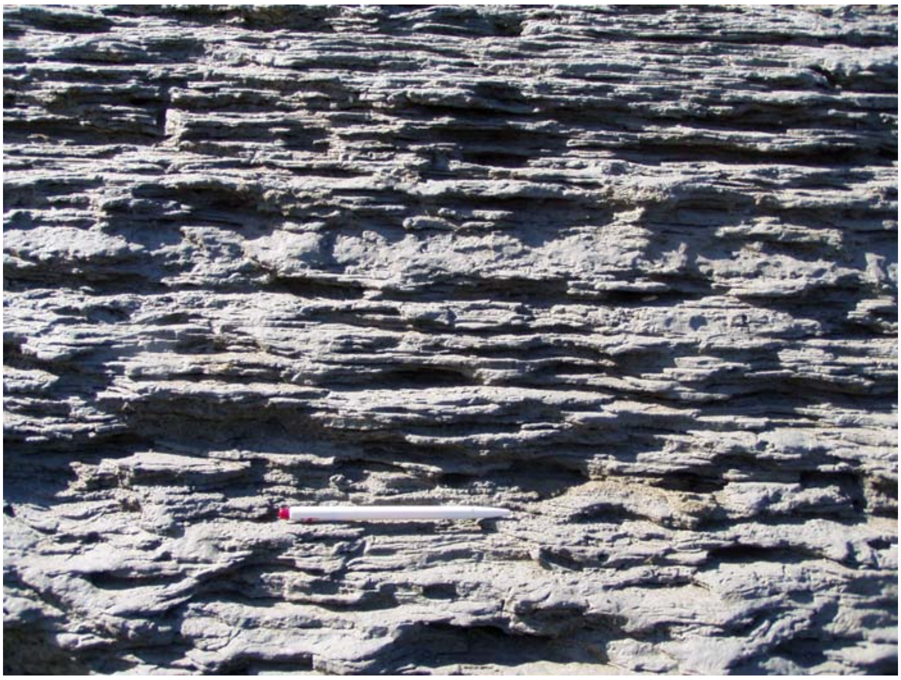

Figure 8. Streaky and lenticular lamination at Okehu Bluff section. Pen is 14 cm long.

DAY 1:

Terraces and Marginal-Marine Sediment Cycles

STOP 1: Vinegar Hill Tephra within Maxwell Group exposed at Brunswick Road *(R22/779503)*

Vinegar Hill Tephra on Brunswick Road occurs as a c. 12-cm thick laterally continuous bed within cross-stratified, highly fossiliferous sandy siltstones (see **Figure 9**) of Lower Maxwell Formation (Cycle 19). This tephra has a weighted mean (n=2) glass isothermal plateau fission-track (ITPFT) age of 1.75 ± 0.20 Ma (Pillans et al. 2005). This age is consistent with correlation of Cycle 19 with MIS 61 and an astronomical age of 1.75 Ma. Marine sediments of Lower Maxwell Formation are truncated by the Brunswick wave cut surface (310 ka, MOI 9) which is overlain by marine and coastal sediments passing upwards into a loess-paleosol sequence with intercalated tephra and dune sand.

Figure 9. Vinegar Hill Tephra occurs as a c. 12-cm thick laterally continuous bed within cross-stratified, highly fossiliferous sandy siltstones of Lower Maxwell Formation. Note the extensive burrowing and sharp but irregular upper and lower contacts. (Photo: *B.V.Alloway*).

STOP 2: Interbedded loess and paleosol layers on a pre-Marorau Terrace at Rangitatau East Road *(R22/767594)*

This outcrop is cut through the highest preserved marine terrace tread remnants found in Wanganui Basin, which rest on (and predate) the Marorau Terrace surface (~Marine Isotope Stage 17, see below).

The outcrop contains 11 loess layers from five major glacial cycles separated by paleosols and punctuated by both rhyolitic and andesitic tephra layers. Rangitawa Tephra, within Loess L10, is zircon fission track dated at 350 ± 50 ka at this locality, in MOI stage 10 (Pillans et al. 1996). The entire sequence is thought to span over the last 500 ka. A detailed stratigraphy and the use of the four physical and chemical parameters enables a climatic interpretation, and a correlation with the MOI record, to be made (see **Figure 10**; from Palmer and Pillans, 1996).

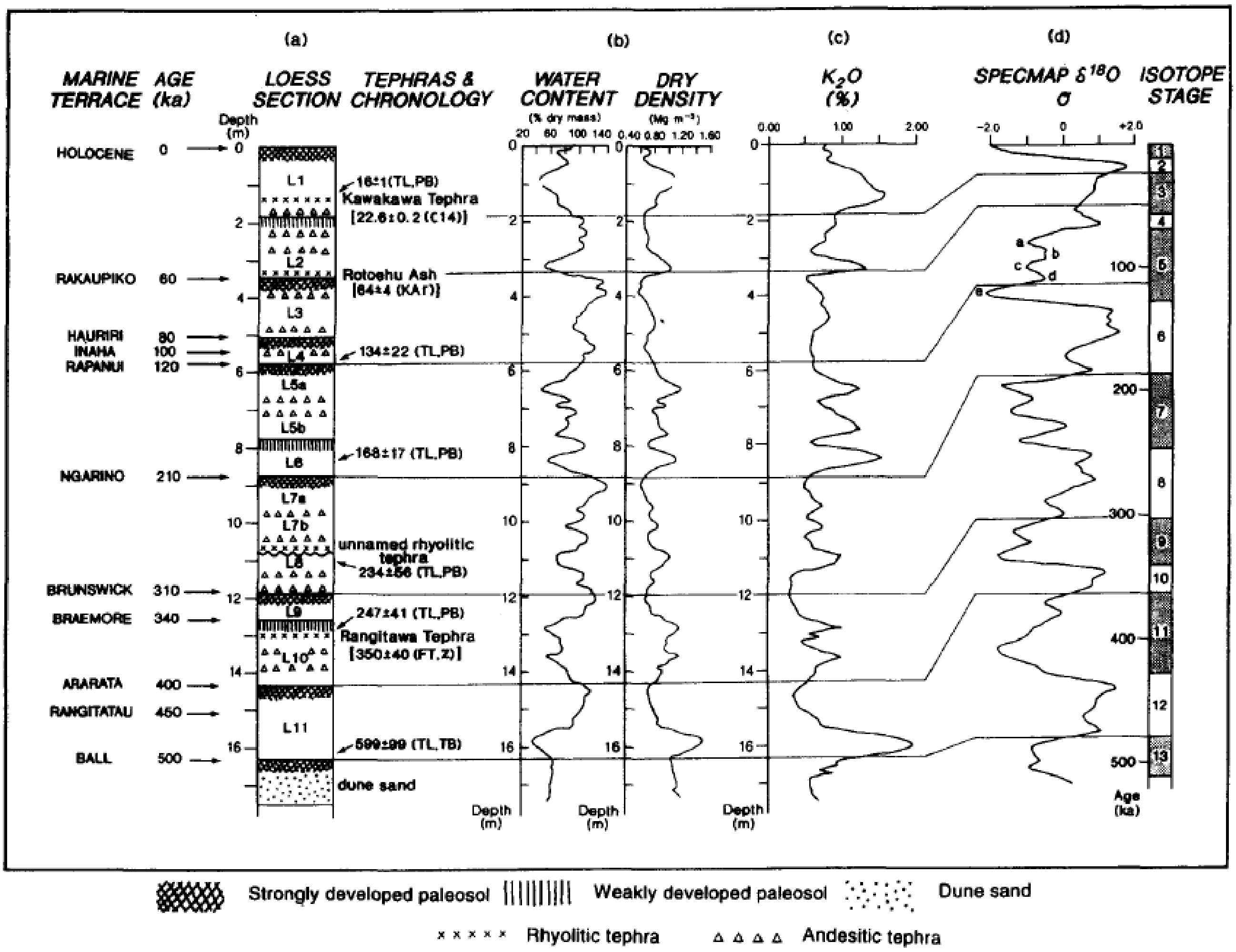

Figure 10. (a) Stratigraphic column for the Rangitatau East section and core. Symbols are explained in the key. Marine terrace ages are from Pillans (1990). Tephra dates are in ka followed by method: C^{14} = carbon-14 dating (Wilson *et al.*, 1988); KAr = potassium-argon (Wilson *et al.*, 1992); FT, Z = fission-track dating of zircons (Kohn *et al.*, 1992). Other dates are thermoluminescence (TL) dates using either partial bleach (PB) or total bleach (TB) techniques (Berber *et al.*, 1992). (b) Water content and dry bulk density (DBD) variations with depth. Errors for DBD are estimated to be ±0.02 Mg/m^3. (c) Potassium variation as K_20 with depth. Errors are estimated to be ±0.1%. (d) SPECMAP MOI curve and isotope stages (Imbrie *et al.*, 1984), Parameters (b) and (c) are determined primarily by weathering. Correlations between the stratigraphy, parameters, and MOI curve are shown.

A model for loess-Palaeosols couplet formation in Palmer and Pillans (1996) suggests a relationship between climatic conditions and loess and paleosol formation (Table 3, below).

Table 3. The relationship between accumulation of soil parent materials* and soil formation on marine terraces near Wanganui

COLD (Glacial)	**e.g. MOI 2 and 6**
QF loess >> AV loess >> tephra >> soil formation	
COOL (Glacial)	**e.g. MOI 3 and 4**
QF loess > or = or < AV loess ≥ tephra > soil formation	
MILD (Interstadial)	**e.g. MOI 2/3, 3/4**
Soil formation ≥ tephra ≥ AV loess > QF loess	
WARM (Interglacial)	**e.g. MOI 1, 5, 7**
Soil formation > tephra >> AV loess >> QF loess.	

*QF, quartzo feldspathic; AV, andesitic volcanic.

The Rangitatau East Road locality also provides an extensive panorama of the successively lower and younger marine terraces towards the Wanganui coast (east of Wanganui marine terraces merge with aggradation terraces of the Rangitikei River and become more difficult to recognise). The increasing tilt on the older terraces is clearly visible, and parallels an inland increasing dip in the underlying Pleistocene and Pliocene sediments.

Twelve terraces were recognised and named by Pillans (1983, 1990). Absolute ages are provided by fission-track, radiocarbon and amino-acid racemisation dating and interpolation based on a terrace deformation model. The terraces are:

Rakaupiko	60 ka, stage 3
Hauriri	80 ka, stage 5a
Inaha	100 ka, stage 5c
Rapanui	120 ka, stage 5e
Ngarino	210 ka, stage 7
Brunswick	310 ka, stage 9
Braemore	340 ka, stage 9
Ararata	400 ka, stage 11
Rangitatau	450 ka, stage 11?
Ball [=Kaiatea]	520 ka, stage 13
Marorau	680 ka, stage 17

Sequence Stratigraphy of Castlecliff Section

The fossiliferous coastal cliffs northwest of Wanganui City (see **Figure 11**) comprise the stratotype of the Pleistocene Castlecliffian Stage (1.6 to 0.34 Ma) and form an important global reference section in Pleistocene stratigraphy. The first comprehensive description of the sediments and their constituent fauna was provided by Sir Charles Fleming in 1953 (NZGS Bulletin - Geology of Wanganui Subdivision). In remarkable anticipation of modern stratigraphic thinking Fleming described 10 sedimentary cycles in the Castlecliff section; each bounded by an erosion surface comprising a basal shellbed and shelf siltstone and sandstone and representing water depth changes of up to 50-m. Subsequent sequence stratigraphic interpretations of the coastal exposure revealed ten, 5th and 6th order shallow-marine depositional sequences between 5- and 25-m thick; each comprising a fossiliferous transgressive systems tract, downlap surface, silty highstand systems tract and in some cases a sandy regressive systems tract. Sequences are bounded by sharp planar, wave cut transgressive surfaces of erosion which truncate lowstand terrestrial sediments and the subaerial unconformity. Coeval slope and basin floor lowstand deposits occur in the Giant Foresets Formation (Taranaki Basin).

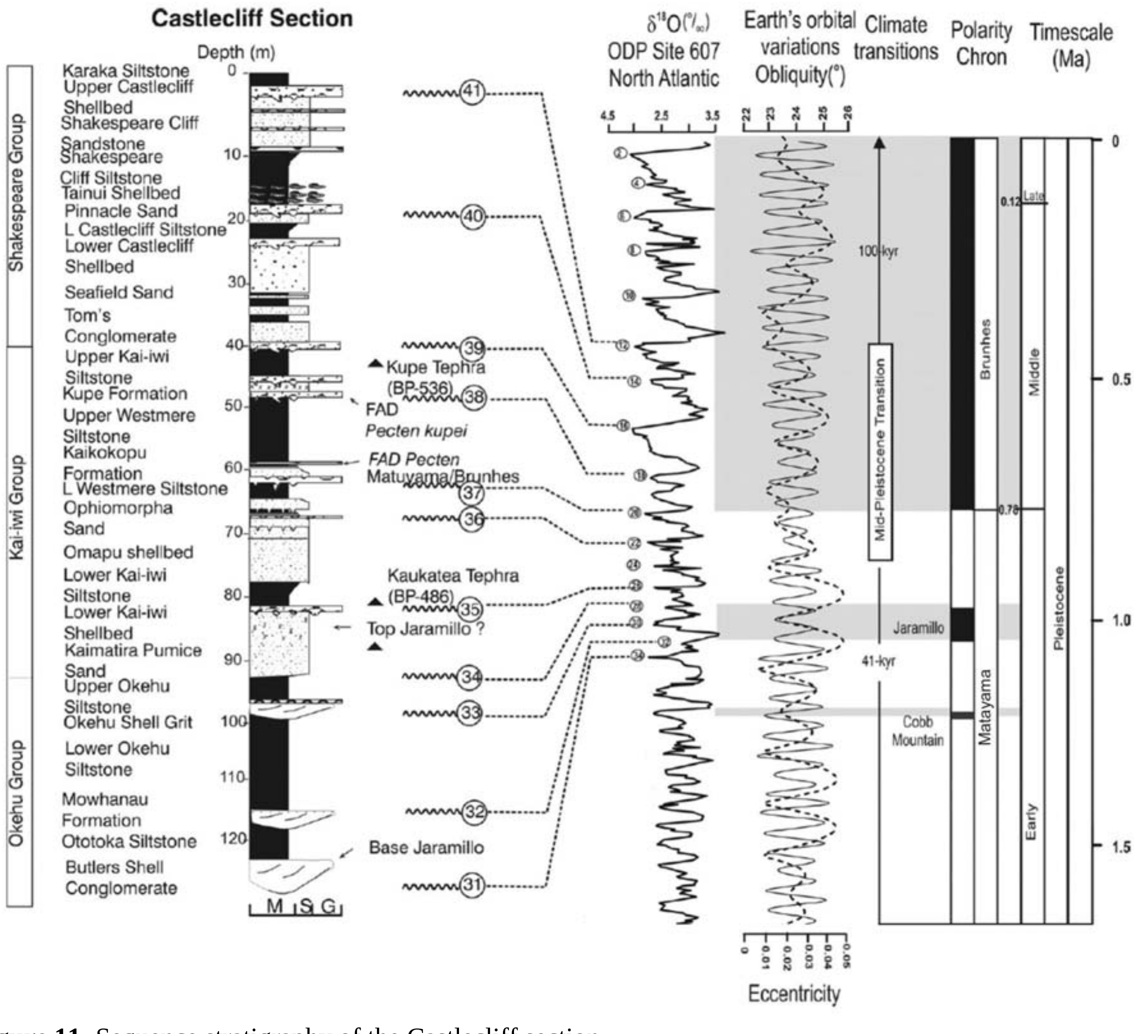

Figure 11. Sequence stratigraphy of the Castlecliff section.

***STOP 3. Butlers Shell Conglomerate unconformably overlying Maxwell Group (Mangahou Siltstone) at Ototoka Stream** (R22/669472) **& type section of the c. 1.75 Ma Ototoka Tephra** (R22/674470) (from Naish et al. 2004; Pillans et al. 2005)**.*

Exposures of Butler's Shell Conglomerate at the base of Sequence 31 (Oxygen Isotope Stage 33, 1.15 Ma) overlie a channelled surface on top of estuarine shell-beds of the Upper Maxwell Group (Sequence 21, Oxygen Isotope Stage 57, 1.65 Ma) (see **Figure 12**). Correlation with inland sections and an integrated tephro- and magnetostratigraphy indicate a significant unconformity at the base of the Butlers Shell Conglomerate spanning c. 1.15 to 1.65 Ma. Sequences 22-30 are missing in this part of the basin equivalent to Oxygen Isotope Stages 55-32. The unconformity is of local tectonic origin. The sequence boundary at the base of the Butlers Shell Conglomerate is locally limonite stained, and marked by an eroded surface which cuts down to the north by at least 10-m over the width of the outcrop. The sequence boundary can also by traced over 10-km's down dip in subsurface high resolution seismic data. The surface is a ravinement surface that coincides with the old stratotype for the base Castlecliffian Stage. The SSP for the Castlecliffian stage has been redefined at the Ototoka Tephra which lies just above the highest occurrence of key Nukumaruan molluscan genera (*Patro*, *G1ycemeris*, *Eumarcia*).

The Butlers Shell Conglomerate is a typical shallow-marine Type A (or Onlap) transgressive shellbed, comprising broken and worn shells of a variety of shallow marine molluscs, greywacke pebbles, that are cross-stratified with mud-drapes. The underlying Maxwell Formation comprises sequences displaying marginal marine to non-marine coastal plain/paralic facies and includes the Ototoka Tephra ITPFT-dated at 1.71±0.32 Ma (astronomically calibrated age of 1.64 Ma MIS Stage 57) which helps to constrain the age range of the superjacent unconformity.

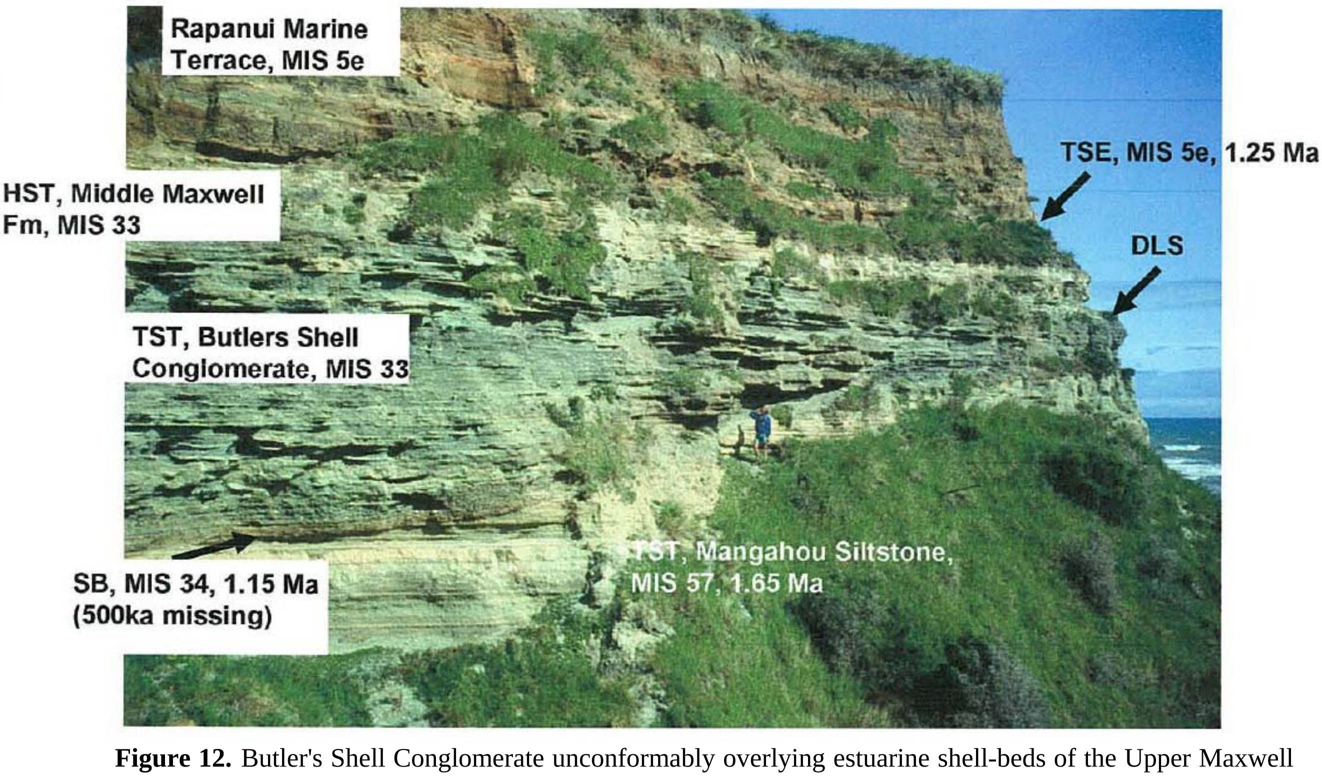

Figure 12. Butler's Shell Conglomerate unconformably overlying estuarine shell-beds of the Upper Maxwell Group at Ototoka Stream (R22/669472). The type section of Ototoka Tephra is exposed in coastal cliffs at R22/674470, some 0.7 km east of Ototoka Stream.

***STOP 4. Castlecliffian coastal stratigraphy at Okehu Bluff, Kai-iwi** (R22/687472)*

A spectacular series of Mid-Pleistocene sedimentary cycles are exposed in the cliffs at Kai-iwi Beach (see **Figures 1 & 13**). The sediments dip at between 2- to 3-degrees to the south; therefore progressively older sediments are exposed to the west along 10-km's of the coastal outcrop. Following a short walk northwest to Okehu Stream we will examine a spectacular outcrop at Okehu Bluff. The contact of Sequences 32 and 33 is well exposed in low cliffs on each side of the stream-mouth, where a sharp, wave-planed surface separates unfossiliferous Lower Okehu Siltstone from the overlying cross-bedded Okehu shell grit. The upper parts of the shell grit are overlain by the condensed *Tiostrea-Dosina* Bed and 5-m of shelf Upper Okehu Siltstone. The siltstone is overlain unconformably by a thick transgressive succession comprising muddy heterolithic wavy-laminated siltstone and sandstone (innermost shelf which passes upsection into a conspicuous unit, the Kaimatira Pumice Sand which displays giant trough cross-bedded volcaniclastic sandstone with mud drapes and superimposed lenticular-bedded, wave-rippled sand. The top of the Kaimatira is well-exposed about 15-m above beach level and comprises a 2-m thick *Paphies* shell-bed, overlain by an intensely burrowed surface marking the sequence boundary/ravinement surface at the base of Sequence 35. The Kaimatira Pumice Sand is a coastal correlative of the Potaka Pumice, which has a glass-ITPFT age of 1.00 ± 0.03 Ma (Pillans et al. 2005).

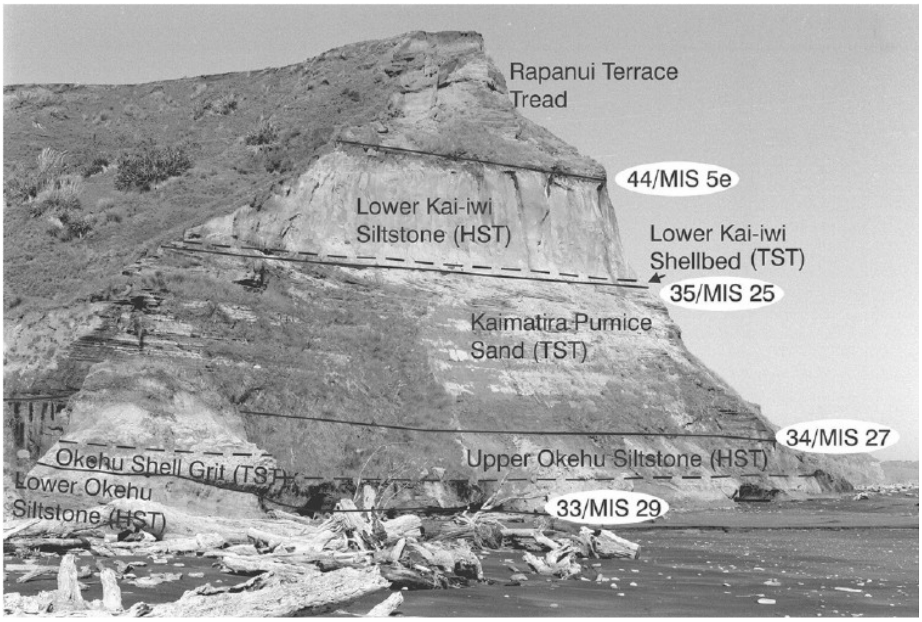

Figure 13. Sequence stratigraphy exposed at Okehu Bluff (see also Figure 1).

Chronostratigraphy

Historically, tephra have played a significant role in the establishment of a chronology for the Wanganui Basin. Radiometric ages have provided independent age control for the bioevents used for Plio-Pleistocene correlation (Seward, I974a; Beu and Edwards, 1984). The tephra also provide mappable isochronous surfaces within the sediments and across the basin. Early attempts at fission-track dating of volcanic glass from Wanganui Basin (Seward, 1974a, 1974b, 1976; Boellstorff and Te Punga, 1977) and zircon (Seward, 1979) produced ages that were largely consistent with the early magnetostratigraphic interpretations (Seward et al., 1986). However, more recent magnetostratigraphies (Turner and Kamp, 1990; Pillans et al., 1994), together with new fission track (Kohn et al., 1992; Alloway et al., 1993; Kamp unpublished data) and $^{40}Ar/^{39}Ar$ (Shane, 1994) ages, have necessitated substantial revision of the chronology of the Pleistocene strata in the basin, as summarised by Pillans et al. (1994) & Alloway et al. (2004). The original fission-track ages on glass were not corrected for partial track annealing, and consequently are now regarded as underestimated, or minimum, ages (Alloway et al., 1993; Pillans et al. 2005; Westgate et al. 2006).

Day 2:

Stop 5. East Fordell *(S22/027378) (from Bussell & Pillans, 1992; Carter et al. 1994)*

This exposure of Wanganui cycles 4-7 encompasses the Kaikokopu Formation (TST-6) (**Figure 14**). As at the coast, the Brunhes/Matuyama magnetic boundary occurs at the base of this unit (Pillans et al., 1994). The coverbeds of the Brunswick terrace outcrop above the mid-Pleistocene section, and contain a bipartite transgressive stratigraphy. Bussell & Pillans (1992) correlated the marine erosion surface at the base of the terrace sequence with oxygen isotope stage 9c (c.340 ka). The swamp deposits within which the Fordell Ash is contained are correlated to substage 9a (c. 310 ka). The upper marine sequence overlies the Fordell Ash, and the second marine incursion onto this terrace must therefore be younger than 310 ka.

Figure 14. Fordell Ash exposed on a road cutting on west side of Kauangaroa Road, east of Fordell (S22/027378). Here, Fordell Ash occurs within terrestrial lignite above marine sediments deposited after the cutting of the Braemore Marine Terrace c. 340 ka (OI substage 9c). (Photo: *B.V. Alloway*).

STOP 6. Pakihikura Tephra exposed in the Turakina Valley *(S22/113408)***.**

Here, Pakihikura Tephra (BP-478/21) occurs within the middle of a 100 to 150-m-thick succession (Cycle 22) of marginal-marine to non-marine carbonaceous muds and tephric sands, which also includes the Birdgrove tephra and several new unnamed tephras (**Figure 15**). The sequence stratigraphic and sea-level signature of the cycle is rather difficult to determine. However, the transgressive base is identified by the occurrence of shallow marine to intertidal facies and *Austrovenus* shellbeds, which pass up into regressive non-marine deposits. Pakihikura Tephra within the upper regressive part of Cycle 22 is correlated with late MIS 55 and early MIS 54 and has an astronomically calibrated age of 1.60 Ma.

Pakihukura Tephra in Wanganui Basin has a glass-ITPFT age of 1.58 ± 0.08 Ma (Pillans et al. 2005) and is consistent with $^{40}Ar/^{39}Ar$ age determinations of two ignimbrite deposits sourced from Mangakino Volcanic Centre. Ages of 1.60 ± 0.03 Ma and 1.55 ± 0.05 Ma for Ignimbrite-A, and 1.51 ± 0.02 Ma and 1.53 ± 0.04 Ma for Ignimbrite-B were obtained by Briggs et al. (1993) and Houghton et al. (1995), respectively. Although Pakihikura Tephra is chronologically equivalent to both Ignimbrite-A and Ignimbrite-B, no definite relationship is confirmed because of limited exposure, partial welding and extensive vapour-phase alteration of these flows.

Figure 15. Pakihikura Tephra exposed in the Turakina Valley (S22/113408) occurs as a c. 5-m-thick succession of pumiceous, dominantly sand-textured volcaniclastics. The base is characterised by a centimetre-thick, texturally distinct, vitric-rich fine sand layer (sole layer, indicated by red arrow) directly overlain by centimetre-thick beds of irregular and stratified planar to low angle cross-bedded, coarse to medium sand-sized vitric ash. Scour and fill, rip-up clasts and dewatering structures occur with fragmented and convoluted millimetre- to centimetre-thick vitric silt laminations. The succession grades upwards to massive silt-sized ash with fine to very fine sand interbeds. The succession suggest emplacement by water-supported mass flow through to hyperconcentrated flow deposits and typify non-marine to marginal marine channels experiencing rapid but intermittent discharge. The absence of bioturbation, desiccation cracks or soil formation suggests very rapid successive emplacement. (Photo: *B.V. Alloway*).

STOP 7. Ototoka tephra exposed in the Turakina Valley *(S22/128415)*

At its type section on the Wanganui coast, Ototoka Tephra lies within wavy-bedded intercalated carbonaceous sandstone and siltstone interpreted as supratidal coastal plain deposition during the regressive phase of Cycle 21 (Abbott et al. 2005). In Turakina Valley, a 20 to 40-cm-thick tephra overlying lignite is correlated with Ototoka Tephra based on glass chemistry and similarity of stratigraphic position (**Figure 16**). An ITPFT-age of 1.72 ± 0.32 Ma was determined for Ototoka Tephra at the Turakina locality (Pillans et al. 2005). The correlation of Cycle 21 with MIS 57 implies a revised astronomically calibrated age estimate of c. 1.64 Ma, which is indistinguishable from the glass ITPFT age.

Figure 16. Ototoka Tephra (BP-559; UT-1164) exposed in the Turakina Valley as a prominent c. 20-cm thick airfall bed overlying carbonaceous muds of Cycle 21. Ototoka tephra has been truncated and is overlain by marginal marine tephric sands and pumiceous gravels. (Photo: *B.V. Alloway*).

STOP 8. Mangaweka Mudstone, State Highway 54 *(T22/522508) (from Journeaux et al., 1996; Naish et al. 1996)*

The Rangitikei River valley contains a ~750-m thick, mid-Pliocene (c. 3.5-2.5 Ma cyclothemic marine succession. The upper seven siltstone-dominated cycles are assigned to the Paparangi Group, which in eastern Wanganui Basin comprises Mangaweka Mudstone (see **Figure 17**). High-resolution textural and microfaunal analyses through the Mangaweka Mudstone indicate regular changes in water depth from outer neritic/upper bathyal to mid/outer neritic environments. The 80 to 100 ka duration of the cyclothems is consistent with a glacio-eustatic origin and corresponds to an interval of progressive climatic deterioration before the initiation at c. 2.54 Ma of major continental Northern Hemisphere glaciations.

Two closely spaced macroscopic tephras have been described within Mangaweka Mudstone (in Cycle M7) by Naish et al. (1996) and named Eagle Hill (upper) and Kowhai (lower) Tephra respectively (see **Figure 18**). These tephra are estimated to have been deposited c. 2.88 Ma in Isotope Stage G14. A third rhyolitic tephra (informally named *Tiny Tim tephra*) closely underlies Kowhai Tephra (Alloway, unpublished data). All three tephra are considered to be too old to be sourced from the Taupo Volcanic Zone and are probably distally sourced from the Coromandel Volcanic Zone.

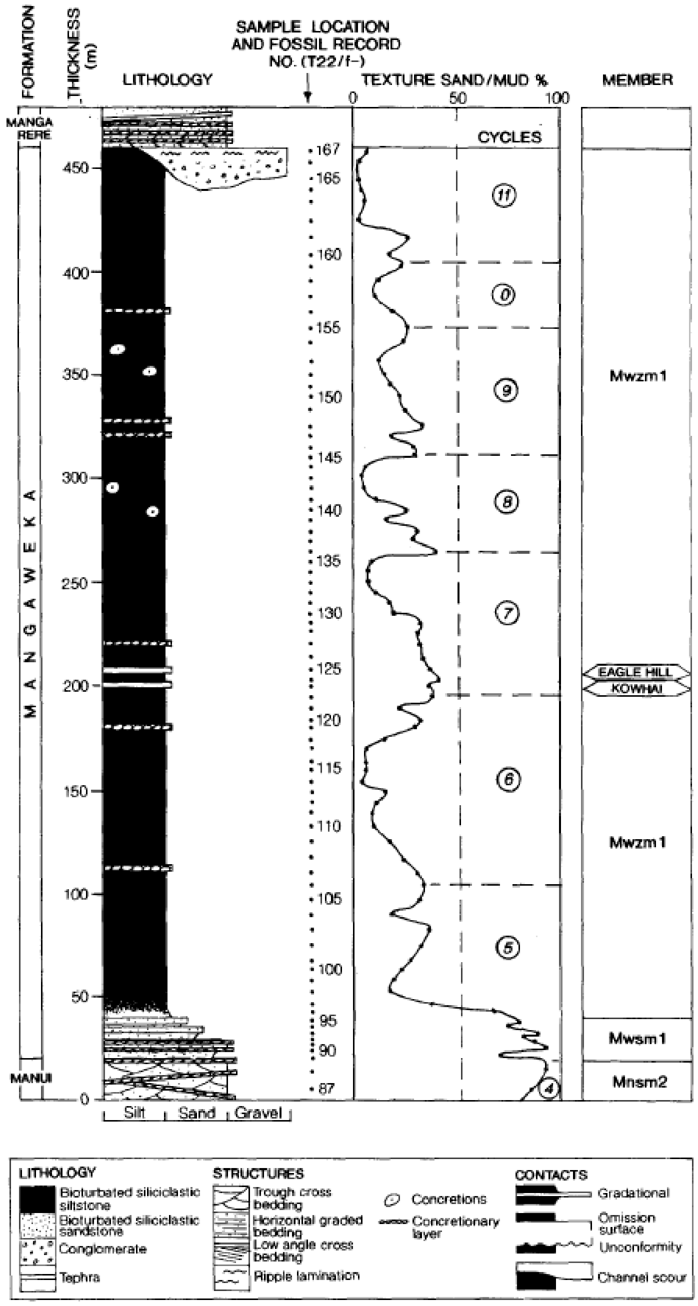

Figure 17. Mangaweka Mudstone stratigraphy (*after* Journeaux et al., 1996).

Figure 18. A. Eagle Hill Tephra (EH) and Kowhai (Ko) Tephra within Mangaweka Mudstone in the vicinity of Mangaweka township. **A**. As observed from the Rangitikei River Bridge; **B.** Cutting on south side of State Highway 54, 1.5 km east of Mangaweka township (Type Section, T22/517509, Naish et al. 1996). (Photos: *B.V. Alloway*).

Stop 9. Otara Road, Rangitikei Valley – Late Pliocene 6th order (41 ka) sequences (T22/427445)

Spectacular outcrops of up to 70m-thick Late Pliocene shelf sequences occur in the deeply incised walls of the Rangitikei River at the township of Ohingaiti. Sequences spanning MIS 100-88 will be viewed from the river by jet-boat. Typically the sequences comprise a condensed transgressive shell-bed (less than 1m thick overlain by a 20- to 60-m thick conformable shelf to shoreface succession of siltstone grading up into well sorted stratified sandstone representing highstand and early regressive phases of sea-level. Sequences accumulated during a phase of rapid basinal subsidence, high sediment supply and recurrent large amplitude (up 100-m sea-level cycles associated with the onset of major 40-kyr ice ages in the northern hemisphere).

A simple model shear stress model has been applied to two of these sequences (e.g. **Figure 19**) in order to semi-quantify paleowaterdepth and the results compared to more established methods of paleo-depth reconstruction (Dunbar & Barrett, 2005).

The sequence boundary, transgressive shell-bed (Tuha Shell-bed, downlap surface and highstand siltstone of sequence 3 (MIS 97 can be accessed in a road cut on Otara Road). This shell-bed contains the cold water scallop *Zygochlamys delicatula*. However its first occurrence is a cycle lower in the Hautawa Shell-bed at the base of Sequence 2 (MIS 98-97 and marks the traditional base of the Pleistocene in New Zealand.

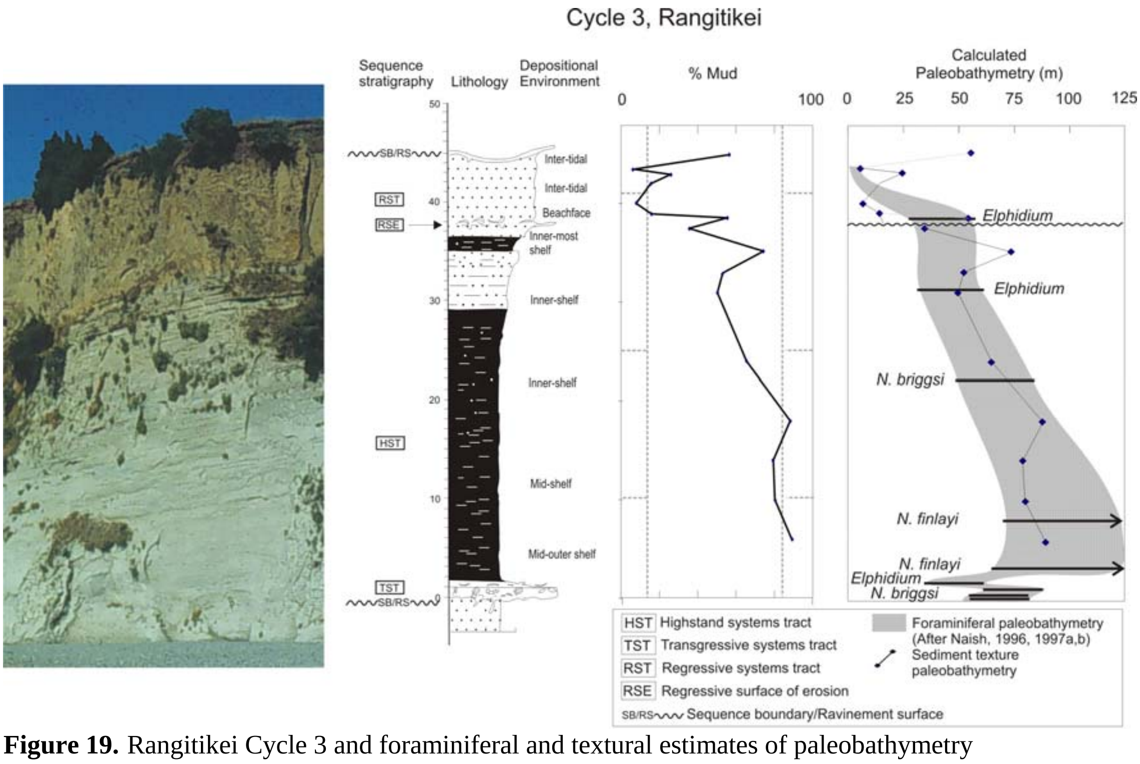

Figure 19. Rangitikei Cycle 3 and foraminiferal and textural estimates of paleobathymetry

Stop 10. Stormy Point – Impressive view (hopefully) of the Rangitikei fluvial terraces *(T22/427445)*

This stop provides a panoramic view of the Rangitikei River valley (see **Figure 20**) and associated terraces. Originally, fourteen sets of river terraces were originally mapped by Milne (1973a). These were (in order of increasing age): Kakariki, Onepuhi, Rewa, Bulls, Ohakea, Vinegar Hill, Rata, Putorino, Powera, Cliff, Greatford, Marton, Burnand and Aldworth. However, only the major terrace sets (Ohakea, Rata, Porewa, Greatford, Marton, Burnand, and Aldworth) are considered aggradational, having formed during episodes of cool or cold climate. Each aggradational surface generated loess that was distributed onto older, adjacent surfaces. Hence, an increasing number of loess sheets with intervening paleosols (representing negligible loess accumulation during episodes of warm climate) progressively occur on older and more elevated terraces. Seven loess's within the Rangitikei have now been recognised (Pillans 1988): Ohakea, Rata, Porewa, L4, Marton, Burnand, Aldworth and Waituna. Critical to the chronology of loess within the Rangitikei is the occurrence, near the base of the loess sequence, of Rangitawa Tephra, a widespread rhyolitic tephra dated at c. 340 ka (Pillans et al. 1996).

Figure 20. Panoramic view of the Rangitikei River valley terraces from Stormy Point. All major aggradational terraces (youngest to oldest: Ohakea, Rata, Porewa, Greatford, Marton, Burnand, and Aldworth) can be observed from this point.

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