It's Our Fault – Past Subduction Zone Ruptures: Task Progress Report 2007-08

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The aim of the Past Subduction Zone Ruptures task is to use onshore geological records to investigate the timing and size of past ruptures of the subduction interface beneath the Wellington region. A large earthquake on the subduction interface beneath Wellington is potentially one of the greatest hazards for the region with not only strong shaking possible but also subsidence, uplift and tsunami inundation of coastal areas. One of the main techniques for detecting evidence of past large subduction interface earthquakes is to document the sudden (coseismic) vertical deformation that occurs in such earthquakes. Where this vertical deformation occurs at the coast there can be significant changes to coastal waterbodies as the relative sea level rises or falls; such changes may be preserved in the geologic record and this is what we have searched for in the Wellington region. To date we have investigated three locations in the Wellington region: Big Lagoon (near Blenheim), the lower Wairarapa Valley and the Pauatahanui Inlet.

Our study shows that Big Lagoon has tectonically subsided since eustatic SL stabilisation, approximately 7,000 years before present. From the four cores collected to date we have developed a good record of paleoenvironmental evolution for Big Lagoon; however we cannot presently we cannot say whether the tectonic subsidence of Big Lagoon has been gradual or coseismic, and if coseismic, we cannot distinguish between upper plate and subduction interface events. In the upper parts of two cores there may be evidence of coseismic subsidence related to the 1855 or 1848 historical earthquakes. The paleoenvironmental data from all cores also constrains the coseismic displacement of any possible earthquakes in the past 6 ka to less than 1 m. Because we have firm evidence, from radiocarbon data, that Big Lagoon has tectonically subsided we will pursue further studies in the locality this coming field season and use the data collected from the existing cores to guide the locations of new cores.

Drilling was undertaken in the lower Wairarapa Valley based on previously existing evidence of rapid subsidence in this area. Two cores were collected from the southeastern side of Lake Wairarapa. The cores are dominated by intertidal clays and silts indicating the lower Wairarapa Valley was a marine inlet up until approximately 3,200 years before present. Radiocarbon ages and paleoenvironmental data from our cores indicate that Holocene subsidence rates of up to 6 mm yr^{-1} in are very unlikely for the lower Wairarapa Valley. However, it has not yet been determined if there is subsidence of the lower Wairarapa Valley, and if there is, at what slow rate it is occurring at. We are currently waiting on more radiocarbon data to resolve this.

Three cores were obtained from the northern margins of Pauatahanui Inlet. Drilling was undertaken here based on modelling that suggested this area may subside in a subduction earthquake. The cores from Pauatahanui Inlet do not show evidence of tectonic subsidence, nor do they hold a marine sediment sequence suitable for studying relative SL changes. This provides some geologic constraints on future modelling scenarios of subduction earthquakes.

1.0 INTRODUCTION

This report is a compilation of scientific results obtained during the 2007-2008 financial year for the Past Subduction Zone Ruptures (PSR) Task of the It's Our Fault Project (IOF). The aim of the Past Subduction Zone Ruptures Task is to use onshore geological records to investigate the timing and size of past ruptures of the subduction interface beneath the Wellington region.

The interface between the Pacific and Australian tectonic plates lies at a depth of 20-25 km beneath Wellington city (Robinson, 1986). The plates are moving relative to each other at rates of c. 40 mm/yr (DeMets et al., 1990, 1994) but it is as yet unknown whether this movement is achieved episodically in large earthquakes or more gradually. A large earthquake on the subduction interface beneath Wellington is potentially one of the greatest hazards for the region with not only strong shaking possible but also subsidence, uplift and tsunami inundation of coastal areas.

One of the main techniques for detecting evidence of past large subduction interface earthquakes is to document the sudden (coseismic) vertical deformation that occurs in such earthquakes. Where this vertical deformation occurs near the coast, large magnitude changes in coastal environments are sustained through movement of the land relative to sea level, and these changes can sometimes be recognised thousands of years later in the geological record (see 2006-07 PSR Task progress report, Cochran and Wilson, 2007). We have used a combination of previous geologic and historic data that indicates where coastal uplift or subsidence has occurred in the past along with modelling of deformation produced by theoretical subduction zone earthquakes to guide our investigation of subduction zone ruptures in the greater Wellington region (Figure 1).

During the 2006-2007 financial year work undertaken for the PSR Task focussed on the collection and study of coastal wetland cores from the Wairau Valley (specifically, Big Lagoon). In the 2007-08 year we have continued with our analysis of the Big Lagoon cores and have developed a high resolution paleoenvironmental record from these cores. The 2007-08 field season saw the collection of new cores from the Wairarapa Valley, where high rates of Holocene subsidence had been previously documented, and from Pauatahanui Inlet, where modelling of subduction zone earthquakes predicted coastal subsidence would occur (Figure 1). This report presents the paleoenvironmental record from Big Lagoon, documents results obtained to date from 2007-08 field work in the Wairarapa Valley and Pauatahanui Inlet and discusses future work plans.

2.0 BIG LAGOON

Big Lagoon is located at the southeastern side of the Wairau Valley (Figure 2). Big Lagoon is part of a large lagoonal complex that consists of Big Lagoon, Upper Lagoon and Chandler's Lagoon (though for simplicity we refer to the whole site as Big Lagoon). Previous work around the southern margins of these lagoons has documented the occurrence of Holocene (the last ca 10,000 years) subsidence at rates of over 4 mm/yr, although up to 40% of this was attributed to sediment compaction (Ota et al., 1995). Water-well data compiled by Brown (1981) also indicated late Quaternary surfaces beneath the lower Wairau Valley (Figure 2).

Four cores have been obtained to date from Big Lagoon; cores BLC6, BLC8 and BLC12 were collected by GNS Science and core BL1 was collected by Geomarine Research. In our 2006-2007 report we had presented the stratigraphy and pollen assemblages from the cores and developed a general low-resolution paleoenvironmental record from the cores; seven radiocarbon dates were also reported. Since that time we have undertaken diatom and foraminifera studies of the cores and we can now present a more detailed paleoenvironmental record from the Big Lagoon cores.

2.1 Big Lagoon paleoenvironmental studies

The purpose of paleoenvironmental studies is to gain an estimate of sea level at the coastal site through time. By comparing the sea level (SL) history at a specific site with a eustatic SL curve (here we use the Gibb, 1986, New Zealand region SL curve) we can determine what component of site-specific SL change is related to global SL changes (i.e. changes in ice volume) and local effects. Local effects in New Zealand are typically related to tectonic changes in land level or to sediment compaction.

The initial step in paleoenvironmental studies typically involves looking at the drill core stratigraphy – specifically the sediment grain size and macrofossils. For example, fine grain sediment suggests a quiet-water environment; whereas, coarse sand and gravels are more typical of tidal channels and beaches; thick peat beds indicate terrestrial environments while shells indicate marine. For greater resolution we use microfossil techniques (diatoms, foraminifera, palynology) to estimate past environments and sea levels. Many species of diatoms and foraminifera microfossils have specific salinity and water depth conditions that they prefer to live in. Similarly the palynology method uses fossil pollen and spores to determine what types of plants lived at or nearby to the site; many wetland plants have specific tolerances to certain tidal inundations or salinity levels thus they can also tell us about the past coastal environment.

2.1.1 Core stratigraphy and chronology

The four cores collected from Big Lagoon consist predominantly of Dillons Point Formation – sands, silts and clays representing the postglacial sea level rise and Holocene stillstand (Figure 3). The cores were collected from near the mean high water level, though accurate elevation surveying has not yet been carried out. Shells appear in all the cores at a depth of 1.5 to 2.5 m. All the cores, except BL1, end in gravel or coarse sand; these basal coarse sediments probably represent early Holocene fluvial conditions or beaches.

Seven radiocarbon ages have been obtained from the four cores. Ages range from c. 2000 to 8500 cal. years BP (Table 1) and indicate that core BLC6 spans the early to late Holocene and cores BLC12, BLC8 and BL1 span the mid to late Holocene (Figure 3). All samples consisted of marine and estuarine shells.

2.1.2 Foraminifera

Sixty-one samples from the four Big Lagoon cores were analysed for their foraminifera assemblages (Figure 4; Appendix 1). A general shallowing trend through time towards present is seen.

The basal sediments of all cores (excluding the gravels which were not analysed) contain foraminifera from a low tide to subtidal environment. This paleo-inlet had a connection to the open ocean as evidenced by the presence, for example, of Notorotalia species which prefer normal salinity, inner shelf environments (Figure 4).

At between 4 and 5 m depth all cores show a slight shallowing to an intertidal environment; a connection to the open ocean is still maintained though this phase. At around 2 m depth in all cores is a change to either no fauna (cores BLC6, BLC8 and BLC12) or to an intertidal lagoon environment (BL1, Figure 4). From the foraminifera assemblages of BL1, Hayward et al. (2007) suggest this environmental change represents the creation of a link with the Wairau River estuary and closing of the Wairau barrier. Hayward et al. (2007) also see foraminiferal evidence of a slight shallowing in the upper 50 cm of BL1 and a change to the high-tidal brackish salt marsh environment of the present site.

Cores BLC6, BLC8, and BLC 12 do not contain foraminifera in the upper 2 m of the sediment. This may be because there was a different environment at these sites from BL1. However, cores BLC6, BLC8, and BLC12 were collected from slightly higher elevations than BL1 and it may be that the upper parts of these cores have undergone wetting and drying cycles with fluctuating groundwater levels resulting in the leaching out of lagoonal foraminifera (typically more delicate agglutinated species).

2.1.3 Diatoms

Diatom flora of 22 samples from cores BLC6, BLC8 and BLC12 were examined (Figure 5, Appendix 2). There was typically good preservation of diatom species, except in the lower half of BLC6. Diatoms are present in the upper parts of all cores so this data is a good compliment to the absence of foraminifera. The diatom assemblages show general changes from brackish-marine inlet to shallow brackish lagoon with a tidal connection to the ocean, and then to a lagoon with limited open ocean connection towards present day. This general trend of inlet shallowing and increasingly restricted marine circulation is consistent with the foraminiferal record discussed above.

2.1.4 Palynology

Twenty-one samples from cores BLC6, BLC8 and BLC12 were examined for pollen and spores, the results were included in the 2006-07 PSR Task progress report (Cochran and Wilson, 2007). Here we summarise the palynological results from each core (Mildenhall, Report DCM 387/07; Appendix 3 Cochran and Wilson, 2007):

1. *Core BLC12*: Sediment in this core was deposited close to marginal marine conditions throughout its history but the degree of “marineness” decreases upwards as the rate of sedimentation appears to increase. The lack of pollen in the youngest sample at 0.5 m precludes an accurate estimate of age but appears post-European as evidence of fires and rare *Pinus* occurs at 1.68 m (the pollen indicates a high sedimentary rate for the top two samples). If the latter is not a result of burrowing then it suggests a post-European age for the top 1.7 m or more. Salt marshes surrounded the area from and above 2.6 m.

2. *Core BLC8*: Sediment in the top 2 m of this core appears to have been deposited in a terrestrial lagoonal environment with marine conditions apparent below this level. Rates of sedimentation fluctuated markedly throughout the sequence, slow at the top where post-European sedimentation occurs only at 0.1 m and Maori occupation from c. 0.3 m. At 5.9 m charcoal represents a major fire event. Salt marshes and open, muddy ground occurred near the deposition site at all times above c. 3 m

3. *Core BLC6*: The top metre of this core seems to have been deposited in fully terrestrial conditions while the rest of the core has marine sediment, albeit very close to shore. The rates of sedimentation in this core appear to be on average much faster than in the other cores with a generally low to very low number of terrestrial grains per gram of sediment. A gradual decrease in the number of dinoflagellates in relation to terrestrial spores and pollen up the sequence indicates decreasing "marineness" towards the present day. Salt marsh environments are indicated above 2.8 m only. Evidence for European occupation starts at 0.8 m, with the presence of *Pinus* pollen, but Maori occupation is uncertain since below this level forest remains constant is composition.

2.1.5 Summary of Big Lagoon and Upper Lagoon paleoenvironmental evolution

The paleoenvironmental evolution of the Big Lagoon and Upper Lagoon has been summarised in Figure 6. Here we discuss each of the phases in the lagoon history.

- Prior to ~8.5 ka (1 ka = 1000 years ago) the area presently occupied by Big and Upper Lagoon was an alluvial plain. Sea level at this time was approximately 10 – 20 m below present mean SL and the Wairau River and other streams draining into Cloudy Bay extended far beyond the present day coastline.

- Rising eustatic sea levels in the early Holocene saw Big Lagoon inundated by the marine environment. There is a small amount of sediment between 8.5 to 9 m depth in BLC6 that represents subtidal sedimentation in Big Lagoon prior to 8.5 ka. The date of 8596-8404 cal. yrs B.P at 8.5 m depth in BLC6 is anomalous in comparison with the other radiocarbon ages (Figure 8) because it is at the youngest limit of the eustatic SL curve while all the other dates are either near the middle or below the eustatic SL curve (thus indicating subsidence). The 8.5 ka shell in BLC6 may indicate tectonic uplift of the sample, or that eustatic SL was actually at that elevation at 8.5 ka or the shell sample may have been reworked as the marine environment moved landward. There is however considerable uncertainty in eustatic SL elevations prior to 7 ka and at this stage we are not certain why the 8.5 ka shell is at such a shallow depth in BLC6.

- From 8.5 ka to 7 ka Big Lagoon, at the location of BLC6, was a subtidal inlet that had a tidal connection with the open ocean. During this period eustatic sea level was rising, although the microfossil data indicates a barrier must have always been in place because the paleo-Big Lagoon was not exposed to full open ocean conditions.

- The marine environment appears to have inundated Upper Lagoon later than it did at Big Lagoon, probably because of the higher topography, i.e. fluvial gravels occur at 6 m depth in BLC8, compared with 9 m depth in BLC6 in Big Lagoon. Coarse shelly sands and gravels at the base of BLC12 and BLC8 may represent beach or foreshore environments prior to a barrier forming across the Lagoon. Alternatively the shelly coarse sediments may represent reworking of coarse fluvial sediments by rising marine waters. By ~6 ka Upper Lagoon was a subtidal inlet that had a tidal connection with the open ocean, like Big Lagoon. It is important to note that sea level in the New Zealand region stabilised at present levels at approximately 7 ka. Therefore the marine inundation of Upper Lagoon probably occurred after sea level stabilisation.

- At approximately 5 ka in Upper Lagoon and 7 ka in Big Lagoon the paleoenvironment changed from a subtidal brackish-marine inlet to an intertidal brackish inlet. Therefore there was a slight shallowing of the relative sea level in these inlets; there was still a tidal connection to the open ocean although the foraminifera suggest this was slightly more restricted.

- The intertidal brackish inlet environment was maintained in both paleo-lagoons until approximately 2 ka. At this time the paleoenvironment changed to an intertidal lagoon with normal salinity to hypersaline conditions. There does not appear to be an associated relative SL change. Rather the change in conditions was probably due to closing of the Wairau barrier, thus restricted open ocean tidal exchange, and the creation of a connection with the estuarine mouth of the Wairau River (Hayward et al., 2007). Essentially at this time the geography of the present day Big Lagoon and Upper Lagoon complex was created.

- There is a slight shallowing of relative SL in the upper 50 cm of BL1 with a change to the high-tidal brackish salt marsh environment of the present site (Hayward et al., 2007). This same shallowing transition probably occurs at the BLC8 and BLC12 sites in Upper Lagoon but we lack the foraminiferal evidence in these cores.

- In the upper 25 cm of BL8 is a buried soil. This may represent a small rise in relative SL. A pollen sample from 30 cm depth suggests a freshwater environment nearby but diatom and pollen samples from 8 cm depth (immediately overlying the buried soil) suggest a nearby salt marsh and occasional exposure to brackish water.

In summary, the paleoenvironmental evolution of the Big and Upper Lagoon is one of basin infilling and associated water depth shallowing since the time of early Holocene marine inundation. The following section addresses whether there is evidence of tectonic processes involved in the paleoenvironmental changes.

2.2 Big Lagoon tectonic history

The elevation of the radiocarbon samples obtained from the Big Lagoon cores indicates that tectonic subsidence has occurred in the lower Wairau Valley (Figure 8). All the radiocarbon samples that post date SL stabilisation (c. 7ka) are presently below mean SL although they were deposited at low tide to intertidal water depths (Figure 6 and Figure 8). The two dates we have obtained from BLC6 that pre-date 8.5 ka do not indicate subsidence (Figure 8), however given the considerable uncertainty in the eustatic SL curve prior to 7 ka we will not draw any conclusions regarding tectonic uplift or subsidence from the older dates. We assume that the core tops are at Mean High Water (approximately 0.5 m above Mean Sea Level) and that all dated species were living at 0.5 m below MSL. Further refinement will be possible through surveying of core top elevations which we plan to do next field season when we return to the Big Lagoon area. We are also yet to make corrections for sediment compaction. Given the magnitude of the subsidence (approximately 5-6 metres of subsidence in the last 6 ka) we expect these corrections will make only minor adjustments to our subsidence calculations.

At the Big Lagoon locality we expect the signal of a subduction zone earthquake to be sudden land subsidence; this would translate to a paleoenvironmental signal of a sharp rise in relative SL. Sharp rises in relative SL are not seen in the Big Lagoon cores collected to date (except at the top of BLC8 which will be discussed below). In contrast we see a general trend of relative SL shallowing (Figure 6). However, it must be noted that subsidence has been occurring during the infilling of Big Lagoon because the post-7 ka radiocarbon ages are all at a lower elevation than present mean SL. Two possible interpretations regarding tectonic signals at Big Lagoon are:

(1) Tectonic subsidence of Big Lagoon has occurred gradually and at slower rates than sediment infilling thus we never see a relative SL rise.

(2) Tectonic subsidence of Big Lagoon, by events on upper plate faults or the subduction interface, has occurred coseismically but our core locations did not capture the sensitive and spatially-restricted paleoenvironments required to record such changes.

At present we cannot definitively distinguish between these two interpretations and there is no more analysis we can do on the cores collected to date to resolve this. However, two notable results have been obtained in relation to tectonic events.

Firstly, there is probable evidence of coseismic subsidence in the top of BLC8 (Figure 7). In BLC8 is a soil, formed in a freshwater environment, overlain by approximately 2 cm of silt that was deposited in a wetland occasionally inundated by brackish water. The silt is then overlain by the modern soil. This buried soil may represent tectonic subsidence associated with the 1848 and/or 1855 earthquakes; historic documents suggest both or one of these earthquakes caused subsidence at Big Lagoon (Eiby, 1980; Grapes and Downes, 1997). Radiocarbon data will not provide the age resolution to prove this as the time period is too modern; however pollen data does suggest a mid-1800's date for the change in paleoenvironment. Silt at 30 cm depth in BLC8 (just below the buried soil) contains significant charcoal and the presence a large percentage of bracken spores indicating probable Maori burning (see Appendix 3, 2006-07 PSR Task progress report, Cochran and Wilson, 2007). This pollen assemblage suggests deforestation was underway and Mildenhall (2007) infers the age of the sample would be less than 600 years but more than about 150 years. The silt immediately overlying the buried soil contains introduced *Pinus* pollen indicating a time of European occupation (post-1840). However, caution is needed in interpreting this buried soil as a coseismic subsidence event as it could have been caused by European alteration of the drainage pattern in the area. A method to explore this would be to collect more cores of the upper 0.5 m in the same area as BLC8 to see if the buried soil is consistent over a broad area.

A second result is that we can constrain the size of any possible coseismic subsidence events to have affected Big Lagoon in the past c. 6 ka to having displacement of <1 m. Most of the cores consist of intertidal sediment that has a possible depth range of 0.5 to -0.5 m (mean tidal range of ~1 m). Therefore a coseismic subsidence event would have to cause > 1 m of subsidence to alter the paleoenvironment to a degree that we could reliably detect it in our paleoenvironmental analysis. No SL rises have been detected in the Big Lagoon cores so we are confident that if Big Lagoon has been affected by coseismic tectonic subsidence, related to either upper plate faults or subduction zone ruptures, in the past 6 ka then the magnitude of subsidence was not greater than 1 m.

For the purposes of this type of study we would prefer to have captured paleoenvironments with narrower depth ranges and greater sensitivity to SL changes than intertidal sediments. In future studies at Big Lagoon we will be aiming to collect sediments deposited in mean high water to extreme high water environments to enable detection of events with less than 1 m of displacement. The cores and probe data we have collected to date will be invaluable in guiding the location of future cores. Future cores will be collected as part of the Subduction Earthquake Geology task of the FRST-funded PLT (Plate Tectonics in and around New Zealand) programme at GNS Science.

3.0 WAIRARAPA VALLEY

Drilling for the PSR Task was undertaken in the lower Wairarapa Valley because available geological evidence suggested fast rates of Holocene subsidence (up to 6 mm yr^{-1}) on the southeastern margin of Lake Wairarapa (Figure 9). With the upper plate faults in this region being unlikely to cause such high rates of subsidence (they are predominantly either strike-slip faults or have low slip rates) the cause of rapid subsidence was unknown but potentially related to subduction earthquakes.

Geologic evidence, available prior to drilling, of rapid subsidence along the southeastern margin of Lake Wairarapa came from radiocarbon ages obtained from the Pouawha well in 1980 (Figure 9 and Figure 10). There is some uncertainty about the elevation of the samples; the Fossil Record Forms for the samples record the well site as 1 m above MSL, but preliminary surveys of an area nearby to the Pouawha well by us would suggest an elevation of approximately 3 m. Thus in Figure 10 we give two elevation options for the samples. The radiocarbon samples were all shells; the species were identified by Alan Beu and all assemblages were from an estuarine environment. If we assume that the shells represented an intertidal environment, which is reasonable given they were dominated by *Austrovenus stutchburyi*, then the radiocarbon ages record Holocene subsidence at rates between 0.1 to 6 mm yr^{-1} (Figure 10). This data was treated with some caution for several reasons: firstly, we do not exactly know the depositional environment of the dated shells, secondly, the water well drilling method may have precluded accurate recording of the sample depths, and thirdly, old methods of radiocarbon dating required larger numbers of shells (compared to modern AMS dating) thus the dated shells may have come from a wide depth range. Nevertheless the magnitude of subsidence calculated using the radiocarbon ages is of such rapid rates that it deserved further exploration. Contouring of the last glacial gravels in the lower Wairarapa Valley by John Begg also suggested a subsiding basin centred on the southeastern side of Lake Wairarapa (Figure 9).

Following our reconnaissance field work in the Wairarapa in early 2007 we dated a shell from the Pouawha auger (Figure 9 and Figure 10, reconnaissance auger data previously presented in Cochran and Wilson, 2007). This result was similar to the ~3.5 ka age from the Pouawha well and indicates that the lower Wairarapa valley was an estuarine environment up until ~3.5 ka and secondly that there has been no subsidence since that time. In the 2006-07 PSR Task progress report (Cochran and Wilson, 2007) we stated that “either it is outside the area of rapid subsidence or subsidence occurred between 3500 and 5000 years”. The purpose of our 2007-08 drilling on the southeastern side of Lake Wairarapa was to determine if there is reliable evidence of subsidence in this area and to collect some paleoenvironmental data that might help to constrain where evidence of earthquakes might exist.

3.1 Colton 1 and Pouawha 1 cores

Two cores were collected from the southeastern side of Lake Wairarapa: Colton 1 and Pouawha 1 (Figure 9), both cores reached 18.3 m depth (Figure 11).

The Pouawha 1 core was located at approximately the same place as the Pouawha well; we were aiming to validate the radiocarbon ages collected from the well and collect paleoenvironmental data. From 18.3 m to 4 m depth the Pouawha 1 core consists of silt, clay and silty fine sand with scattered shells, typically articulated *Asutrovenus stutchburyi* or mussel shell layers (Figure 11). The upper 4 m of Pouawha 1 is alternating clays, silts and fine sands, this section contains no shells; there is a small thickness of anthropogenic fill sediment at the top of the core.

The Colton 1 core was located approximately 3 km north of Pouawha 1, closer to the margin of Lake Wairarapa and near the centre of the basin estimated by the last glacial gravel contours (Figure 9). From 18.3 m to 5.4 m depth the Colton 1 consists of very homogenous blue-grey clay with scattered to rare shells (Figure 11). Of note is a 2 mm-thick tephra layer at a depth of 16.4 m. Some saturated well-sorted medium sand was lost from the Colton 1 core between 5.4 and 4 m depth. The upper 4 m of core consists of alternating fine and medium sands, silts and clay.

To date only limited paleoenvironmental data has been studied from the Pouawha 1 core. Eighteen foraminifera samples show generally very poor foraminifera preservation (Appendix 3). There are two clusters of intertidal estuarine foraminifera assemblages c. 7 to 9 m depth and 15 to 16.5 m depth (Figure 11). It is difficult to draw paleoenvironmental conclusions from such limited data and we expect that diatom and pollen samples (currently being processed) will aid in the study. Samples for foraminifera, diatom and pollen studies are also currently being processed from the Colton 1 core. The future studies of the Pouawha 1 and Colton 1 cores is to be undertaken with funding PLT programme.

3.2 Evidence of Holocene subsidence from the Wairarapa Valley cores

We dated both the shallowest and deepest estuarine shell specimens from Pouawha 1 (Table 1, Figure 10). The shallowest sample, from 3.96 m depth, has an age of 3333-3069 cal. yrs B.P., and the deepest sample, from 15.85 m depth, is 7564-7390 cal. yrs B.P (Table 1). The shallow radiocarbon age indicates a subsidence rate of 0.5 ± 0.3 mm yr^{-1} since 3.5 ka (assuming core elevation of 2.2 ± 1 m). This is consistent with the radiocarbon data from the Pouawha well and Pouawha auger (Figure 10). Such low rates of subsidence may be entirely related to sediment compaction.

The deep radiocarbon age from Pouawha 1 indicates a subsidence rate of 1.1 ± 0.2 mm yr^{-1} since 7.5 ka if mean SL was -8 m at this time (in middle of eustatic SL curve uncertainty envelope, Figure 10). Taking into account the large uncertainty in the eustatic SL curve at this time subsidence rates could range from 0.16 to 2.1 mm yr^{-1}. Our radiocarbon age from Pouawha 1 clearly indicates a lower rate of subsidence than the radiocarbon ages from the Pouawha well. Given that we have accurate depth measurements, we suggest the depths of Pouawha well radiocarbon samples are unreliable. Because there is large uncertainty in the eustatic SL curve at 7.5 ka it is difficult to assess whether there has been tectonic subsidence since that time. The low rate of subsidence of 0.16 mm yr^{-1} could be due to sediment compaction but the higher rate of 2.1 mm yr^{-1} is more suggestive of tectonic subsidence plus sediment compaction. To resolve this uncertainty we have submitted a further radiocarbon sample from 10.24 m depth (Table 1). We anticipate this sample will have an age of <7 ka (younger than the time of eustatic SL stabilisation) therefore will allow us to constrain the subsidence rate better. Two radiocarbon samples have also been submitted from the Colton 1 core (Table 1), but the results are not yet available.

3.3 Evidence of Late Quaternary subsidence in the lower Wairarapa Valley

As part of our investigation of the lower Wairarapa Valley we have also been studying the elevation of last glacial (Q2) gravel surfaces in the region to determine if there has been differential uplift or subsidence of this unit since its deposition. A preliminary structure contour map of the Q2 gravel surface produced by John Begg for this task indicated a subsiding basin centred on the southeastern margin of Lake Wairarapa (Figure 9). This is consistent with the morphology of the Ruamahanga River. The Ruamahanga River flows southwest through the Wairarapa Valley and at the Pouawha locality the river does a gradual turn to flow northwards into Lake Wairarapa (the Ruamahanga diversion was created in the 1960’s, Figure 9). It is unusual for a river to make such an about turn in its flow direction; this implies either Lake Wairarapa is subsiding or there was tectonic uplift of the region between Lake Wairarapa and the coast and that river downcutting could not keep pace with the uplift forcing it to change direction. There is evidence from Pleistocene marine terraces of tectonic uplift of the region between Lake Wairarapa and the coast but we are not sure yet how the rates of coastal tectonic uplift and river downcutting have interplayed.

The structure contour map of the Q2 gravels in Figure 9 is based on extrapolation of topographic contours of the surrounding Q2 gravel surfaces. To refine this we have been liaising with the Greater Wellington Regional Council (GWRC) to use their database of water bore logs. GWRC has allowed us access to the logs from the lower Wairarapa Valley and we are in the process of mapping out the top of the Q2 gravel in the subsurface (Figure 13). At this stage we have examined the water bore stratigraphy data, the drillers logs are typically basic descriptions such as “silt” or “water-bearing gravel” and it is impossible to pick out a single correlateable unit across the whole area. We assume that the highest gravel layer of significant thickness (> 3 m) corresponds to the Q2 gravel (Figure 12). We have projected the water bore logs to a smoothed centre line running down the valley (Figure 13). The average position of the top of the Q2 gravels deepens towards the southeast to a maximum depth of 45-50 m (but note there is no age control to substantiate our correlation of Q2 along the profile). Two important preliminary conclusions can be drawn from this data: (1) the Q2 gravels on the southeastern side of Lake Wairarapa appear to be 10 to 40 m deeper than the contours estimated by extrapolation of Q2 surface topography (compare Figure 9 and Figure 13); (2) the Q2 gravels do not appear to rise upward in between Lake Wairarapa and the coastline, perhaps suggesting there has not been uplift of the coastal area relative to Lake Wairarapa since the last glacial, however we do know there has been late Quaternary uplift of the southern Wairarapa coastline from elevated Pleistocene marine terraces.

To assess whether the Q2 gravels in the lower Wairarapa Valley are subsided relative to their depositional elevation we have compared the Q2 gravel depths with the elevation of the Ruamahanga River and the Waiohine terrace surface (Figure 14). The Waiohine terrace in the Wairarapa Valley is a last glacial aggradation surface (Litchfield and Berryman, 2006); it is equivalent to the Q2 gravels. At this stage, we cannot tell if the Q2 gravels have subsided since their deposition. This is because we do not know where the base level of the Ruamahanga River was during the last glacial. If the Ruamahanga River incised down to 120 m below SL (-120 m being the SL during the last glacial max) then the Q2 gravels lie above this level and do not appear to have subsided (Figure 14). However, if the last glacial Ruamahanga River had a base level that was perched above the 120 bathymetric contour (e.g. the shelf edge) then the Q2 gravels may have been initially deposited at a higher elevation than they presently lie at today, hence they may have subsided (Figure 14). Work on this topic is continuing, although it may remain impossible to estimate the base level of Ruamahanga River in the last glacial. We also suspect that there are multiple Q2 and younger gravel units in the lower Wairarapa Valley, in particular many of the fans coming off the Rimutaka Ranges are significantly younger than last glacial (~18 ka). This means our estimates of the Q2 surface from the well logs may have a high degree of uncertainty.

4.0 PAUATAHANUI INLET

The Pauatahanui Inlet was investigated as part of the PSR Task for two reasons: (1) modelling suggested this part of the coastline may subside during a subduction thrust earthquake (Figure 1); and (2) the broad intertidal flats and high tidal salt marshes of the modern Inlet are sensitive to small changes in SL (Figure 15); if such morphology existed throughout the mid-late Holocene then the sedimentary record may be a good recorder of past SL changes.

Some previous work has been undertaken looking at the sedimentary record of the Pauatahanui Inlet. During the 1970’s three cores were obtained from the middle of the Inlet; unfortunately there is limited documentation of these cores. One of the cores is briefly described in Healy (1980) and several radiocarbon dates are presented. From the data presented in Healy (1980) it is difficult to assess whether there is any tectonic signal in the cores – either a signal of subsidence or uplift, or a signal of sudden paleoenvironmental change. Several of the cores were relocated in the GNS core store, however they are mislabelled, dried out and fragmented, thus of no use.

Eight radiocarbon ages, each accurately related to a Holocene SL, from the Pauatahanui Inlet were presented by Gibb (1986). Gibb concluded that the dated SL markers indicated tectonic uplift of the Pauatahanui Inlet at a rate of 0.3 ± 0.04 mm yr^{-1}. Despite this research indicating tectonic uplift of the Inlet contrasting with modelling of potential subduction earthquake deformation predicting subsidence of the Inlet (Figure 1) it was decided to presume drilling at this location. There are a number of upper plate active faults in the Pauatahanui region (e.g. Ohariu Fault) and there could feasibly be uplift in local (upper plate) earthquakes and subsidence in subduction earthquakes with the overall net tectonic signal resulting in uplift.

Reconnaissance field work was undertaken at Pauatahanui Inlet during November 2007. Twelve shallow (< 1.5 m deep) hand augers were collected (Figure 15). The augers showed a predominance of fluvial sediment, such as silty sands and pebbly layers; however, in several augers there was evidence of buried soils and woody layers (Appendix 4). The only location where we found shells was at the seaward margin of salt marsh, at the high water mark. This indicated that either the present margins of the inlet marks the maximum extent of the Holocene marine transgression, or marine sediments may have been deeper than our augers at locations further from the high tide mark. Our aims for the 2008 drilling campaign were therefore to collect cores from as close as possible to the high tide mark, and/or to obtain core from deeper than 1.5 m.

4.1 Pauatahanui Inlet cores

Three cores, named Pauatahanui Orchard, Ration Point A and Ration Point B, and four probe profiles were obtained from Pauatahanui Inlet (Figure 15). The probe data provided a valuable guide for selecting the drill locations as probe resistance measurements give an estimate of the subsurface sediment type. In general, the drilling at Pauatahanui Inlet was difficult due to either very hard sediments or thick gravel layers.

The Pauatahanui Orchard core, reaching a depth of 5.4 m, was obtained from a paddock at the margins of the salt marsh in the northeastern corner of the Inlet (Figure 15). We suspect that this paddock may have, prior to European settlement, been part of the salt marsh but was subsequently drained. From 5.4 to 1.3 m depth the core consists of very stiff silt and fine sandy silt (Figure 16). At the base of the core the silt-dominated sediments shows an increase in angular gravel clasts; deeper drilling was inhibited by the hardness of the sediment and we estimate the 5.4 m depth represents the start of some highly compacted, silty gravel. The upper 1.3 m of core is loose gravel, silt and fine sand (Figure 16). Given the stiff and weathered character of the silt in the lower part of the core we suggest that these are pre-Holocene fluvial silts (e.g. see righthand photo in Figure 17). They may have been deposited during the last glacial period, or perhaps even before that. We have submitted a sample of the silt for palynology processing. Pollen may be able to tell us what the climate was like at the time of deposition, and whether or not it is a glacial-period sediment. At this stage we are not proceeding with any other paleoenvironmental studies of this core as it is not prospective for having a SL record.

The Ration Point A core reaches a depth of 5.6 m; however, core was not collected from 2.9 to 4.8 m because this section was gravel. This core was collected in a paddock near Ration Point on the northern side of the Inlet; the site lies between a relict sand ridge and the road.

On the seaward side of the road is salt marsh (Figure 15). We suggest the relict sand ridge was the former Inlet shoreline before the road was built. From 5.6 to 4.8 m and 2.9 to 2 m the Ration Point A core consists of alternating decimetre-scale peat and sand, or sandy silt, units (Figure 16, and lefthand photo in Figure 17). From 2 to 1.5 m is organic-rich silt with scattered shells, most of the shells are *A. stutchburyi* fragments. Between 1.5 and 1.2 m depth is a silty gravel unit overlain by peat and above 1.2 m the Ration Point A core consists of angular gravel which is probably anthropogenic fill from when the road was built (Figure 16).

The Ration Point B core was collected approximately 10 m away from Ration Point A (Figure 15, and central photo in Figure 17) and reached a depth of 4.2 m (Figure 16). The aim of Ration Point B was to collect a slightly more seaward core and see if the stratigraphy of Ration Point A was reproducible. Probing indicated the upper 1.1 m of sediment was gravel; this section was not collected as we were certain it was anthropogenic fill. The general stratigraphy of Ration Point B is similar to Ration Point A; however, the elevations and thicknesses of the main gravel units appear to differ quite significantly. From 4.2 to 1.8 m the Ration Point B core consists of alternating decimetre-scale peat, silty sand and gravel units. Between 3.7 and 3.3 m depth the peat units are actually tree logs at least 15 cm in diameter (Figure 16). From 1.8 to 1.1 m depth is silty fine sand with scattered *A. stutchburyi* and *P. australis* shell fragments.

Two radiocarbon ages have been obtained from the Ration Point A core; a shell at 1.6 m depth has an age of 6970-7231 cal. yrs B.P. and peat at the base of the core (5.58 m depth) has an age of 8047-8416 cal. yrs B.P. (Table 1, Figure 16). The elevations of the cores have not yet been accurately surveyed but these dates indicate there has been very little or no subsidence of the Pauatahanui Inlet during the Holocene. Unfortunately, the intriguing alternating peat and sand units were deposited prior to eustatic SL reaching the Inlet and these sediments most likely represent flood events within an early Holocene peat marsh. The lower gravel units of the Ration Point cores are likely to be fluvial channel deposits given the large variations in gravel thicknesses and depths between the two cores. Only limited paleoenvironmental data has so far been gathered from the two Ration Point cores. Foraminifera samples show that the sediments containing shells also contain intertidal foraminifera, although the specimens are rare and poorly preserved (Figure 16, Appendix 5). The sand units in between peat beds are all barren of foraminifera, consistent with fluvial deposition. A limited number of diatom and pollen samples are currently being processed from the Ration Point A core.

4.2 Summary of Pauatahanui Inlet results

The Ration Point cores collected from the northern margin of Pauatahanui Inlet do not show any indications of tectonic subsidence or uplift. The cores contain only a small amount of marine sediment that probably represents the maximum Holocene marine transgression at approximately 7 ka. A limited amount of further paleoenvironmental data will be analysed from the Ration Point A core so that we can be certain of the fluvial origins of the sand and peat units below 1.8 m depth. The Pauatahanui Orchard core is probably composed of last-glacial fluvial sediments and it contains no paleoenvironmental data of use to this study. Several vibracores were collected along the northern margins of the Pauatahanui Inlet by Bruce Hayward and Hugh Grenfell (Geomarine Research). Using a vibracorer they were able to collect cores up to 5 m in depth from the intertidal flats. Results from these vibracores have not yet been analysed by Geomarine Research.

5.0 FUTURE WORK

The search for a record of past subduction ruptures, if such a record exists for the Hikurangi margin, is likely to be a long and detailed process. For example, it took several decades of geological work along the Cascadia subduction zone to achieve a good understanding of the subduction earthquake hazard along that margin. In New Zealand such research is just beginning (e.g., Cochran et al., 2006). GNS Science is committed to future studies of the Hikurangi margin subduction earthquake geology through the PLT Programme. The IOF funding has provided a vital catalyst for subduction earthquake research in the Wellington region and the results outlined in the report represent considerable advances in our knowledge. This IOF-funded study has provided the stimulus for the future work we have planned under the PLT Programme:

- WAIRAU VALLEY: In the 2008-2009 field season we plan to return to Big Lagoon and collect more cores. This round of drilling will use the paleoenvironmental data already obtained and the probe data collected in 2007 to guide the location of new drill sites. To capture more sensitive paleoenvironments we need to move further away from the modern margins of the lagoons but this may result in encountering more fluvial gravel. We will probably also collect several short (0.5 m) cores in the area around BLC8 to see if we can trace the buried soil and resolve whether it is related to the 1848 or 1855 earthquake, or human drainage alterations of the site.

- WAIRARAPA VALLEY: We are waiting upon further radiocarbon results from both the Pouawha 1 and Colton 1 cores. These should allow us to better constrain whether there has been Holocene subsidence of the lower Wairarapa Valley, near Lake Wairarapa. We will also progress with paleoenvironmental analysis of the Pouawha 1 and Colton 1 cores. Foraminifera samples from Colton 1 are currently being processed. Diatom and pollen samples from Pouawha 1 are also currently being processed; we will wait to see if they yield useful results from Pouawha 1 before carrying out the same analyses on Colton 1.

- PAUATAHANUI INLET: Some further paleoenvironmental analysis (diatoms and pollen) will be carried out on the Ration Point A core. This is to confirm that the sediments below 1.8 m are of fluvial origin. We will also be collaborating with Geomarine Research as they analyse their cores from Pauatahanui Inlet.

6.0 SUMMARY

The aim of the Past Subduction Zone Ruptures task is to use onshore geological records to investigate the timing and size of past ruptures of the subduction interface beneath the Wellington region. To date we have investigated three locations in the Wellington region: Big Lagoon, the lower Wairarapa Valley and the Pauatahanui Inlet. Drilling was undertaken in the lower Wairarapa Valley based on evidence of rapid subsidence. The data from our cores prove that subsidence rates of up to 6 mm yr^{-1} in the Holocene are very unlikely. It has not yet been determined if there is subsidence of the lower Wairarapa Valley, and if there is, at what slow rate it is occurring at. We are currently waiting on more radiocarbon data to resolve this. The cores obtained from the margins of Pauatahanui Inlet do not show evidence of tectonic subsidence, nor do they hold a marine sediment sequence suitable for studying relative SL changes.

Our study has shown that Big Lagoon has tectonically subsided since eustatic SL stabilisation in the Holocene and from the cores collected to date we have developed a good record of paleoenvironmental evolution. Presently we cannot say whether the tectonic subsidence of Big Lagoon has been gradual or coseismic, and if coseismic, we cannot distinguish between upper plate and subduction interface events. However, we have shown there may be evidence of coseismic subsidence related to the 1855 or 1848 historical earthquakes and our paleoenvironmental data constrains the coseismic displacement of any possible earthquakes in the past 6 ka to less than 1 m. The paleoenvironmental data collected to date from Big Lagoon will be used for guiding the locations of new cores to be collected this summer.

7.0 ACKNOWLEDGEMENTS

Landowners Ted Colton, Frazer Blazek, Judy Preston and Janet and Phillip Reidy are thanked for allowing access to their land for drilling in the Wairarapa and Pauatahanui Inlet. Peter Barker and William Ries operated the drill truck and are thanked for their hard work. Mark and Eileen Hemphill-Haley are much appreciated for their field work assistance during the drilling, and Bruce Hayward and Hugh Grenfell also helpfully joined us in the Wairarapa. The Greater Wellington Regional Council, particularly groundwater geologist Doug McAllister, is thanked for providing well data from the Lake Wairarapa area.

A significant part of this research (including the pollen analysis and some radiocarbon ages) was funded by the Foundation for Research, Science and Technology through a complimentary task that is part of the ‘Plate Tectonics in and around New Zealand’ programme.

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FIGURES

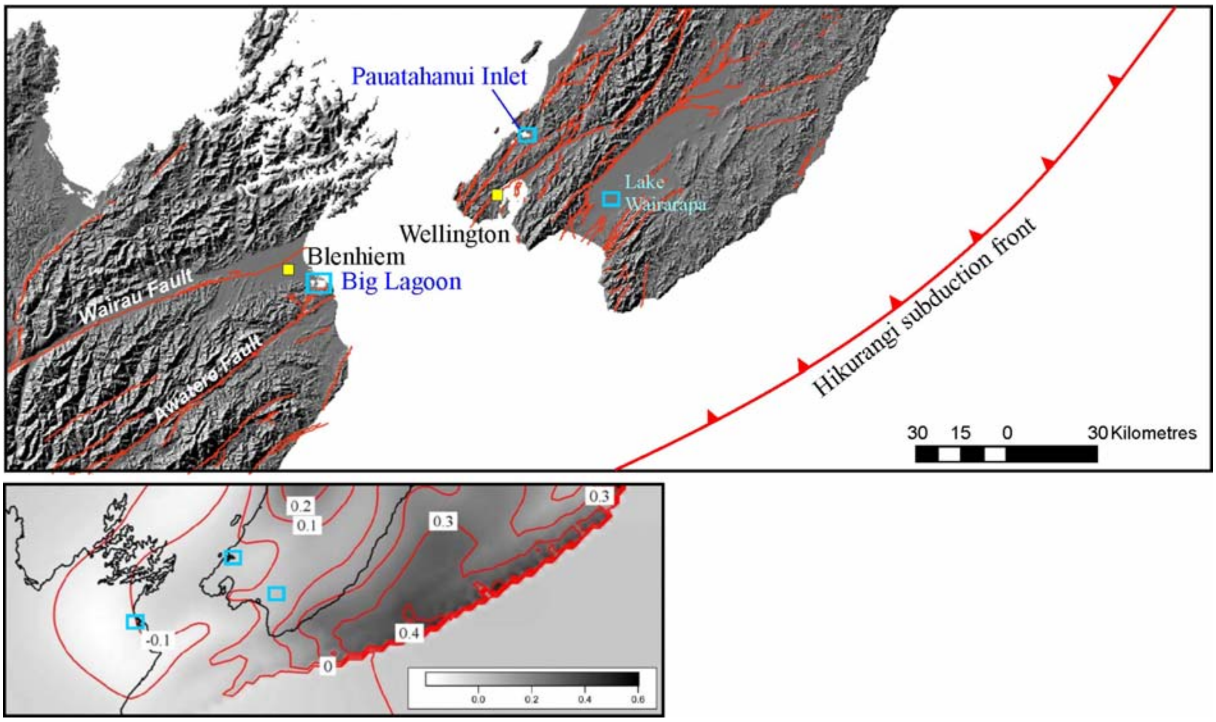


Figure 1 Map of the lower North Island showing locations studied for evidence of past subduction zone ruptures. Also shown in red are the onshore active faults and the offshore Hikurangi subduction trench. Lower figure shows the 0.1 m contours of tectonic deformation for a modelled 100-yr recurrence subduction zone earthquake (for an indication of modelled 500-yr recurrence deformation multiply 0.1 m by 5 = 0.5 m).

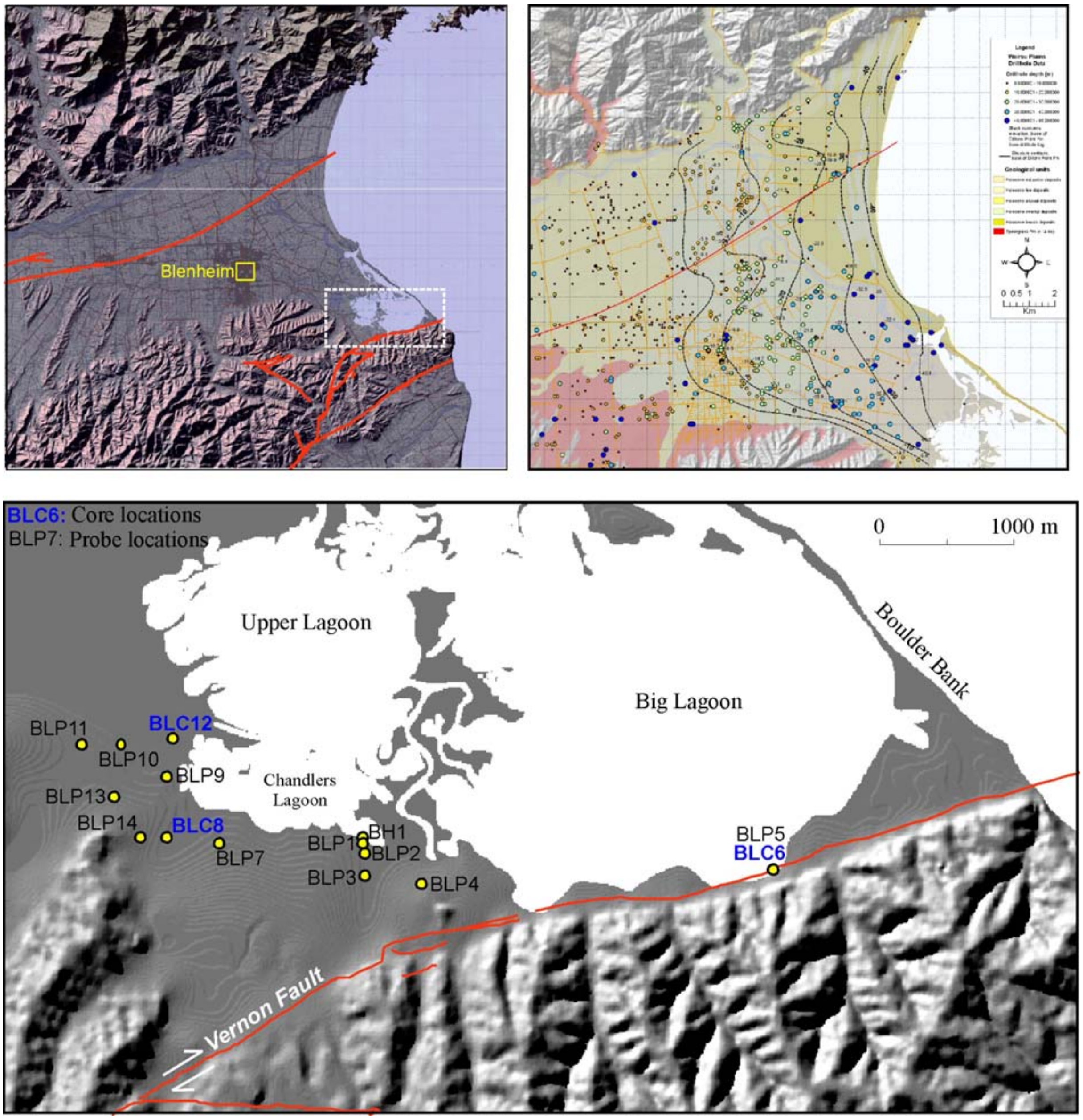


Figure 2 Big Lagoon location maps. Top left figure shows the Wairau Valley region topography and the main active faults (denoted as red lines). Top right figure shows the structural contours on the base of the Dillons Point Formation (c. 8000 years old), after Brown (1981) and modified by John Begg (approximate location of Wairau Fault denoted as red line). Bottom figure shows the drill and probe locations at Big Lagoon.

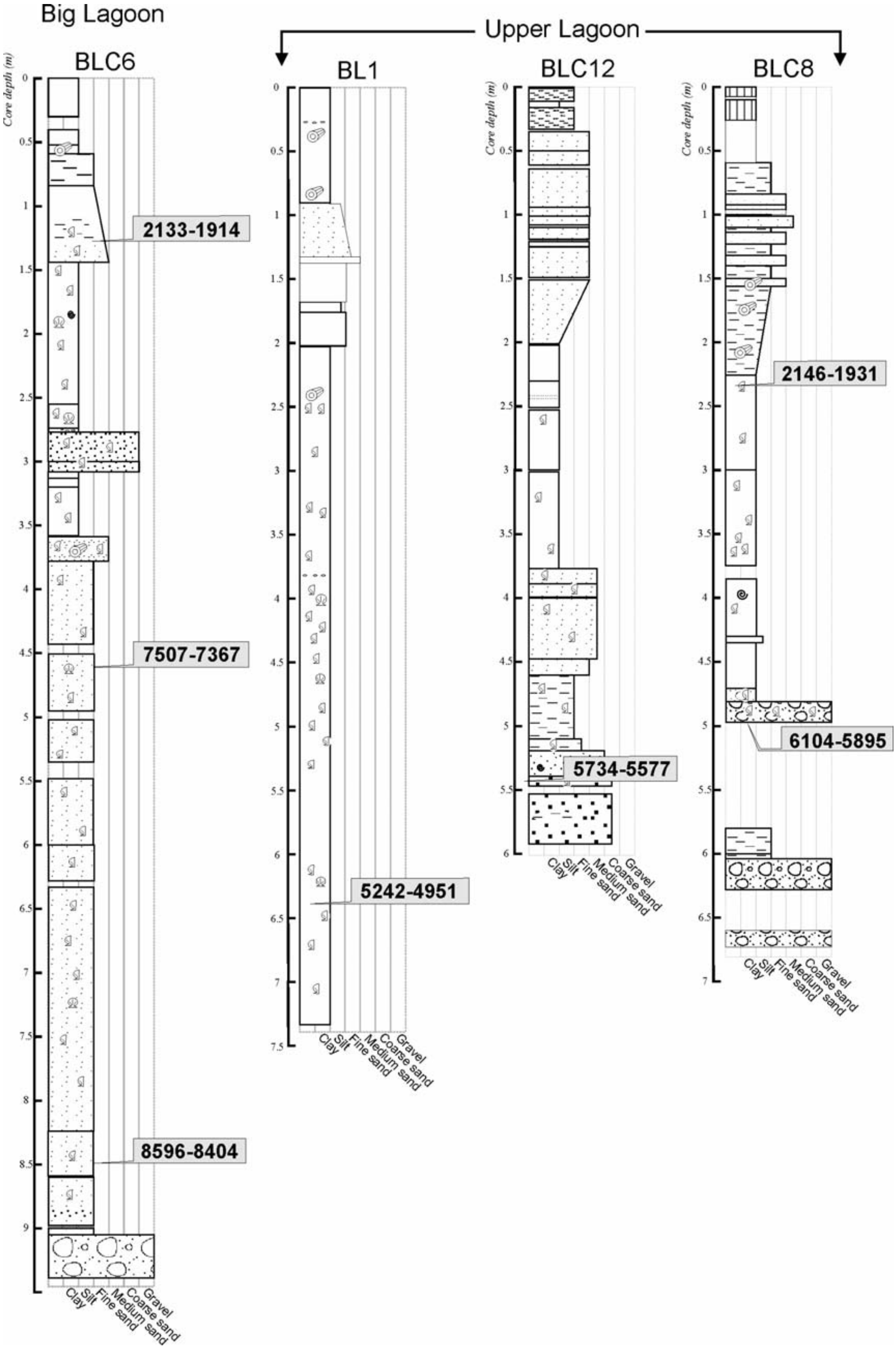


Figure 3 Stratigraphy and radiocarbon ages of the Big Lagoon cores. For detailed stratigraphic descriptions please see Appendix 2 of the 2006-07 PSR Task progress report (Cochran and Wilson, 2007).

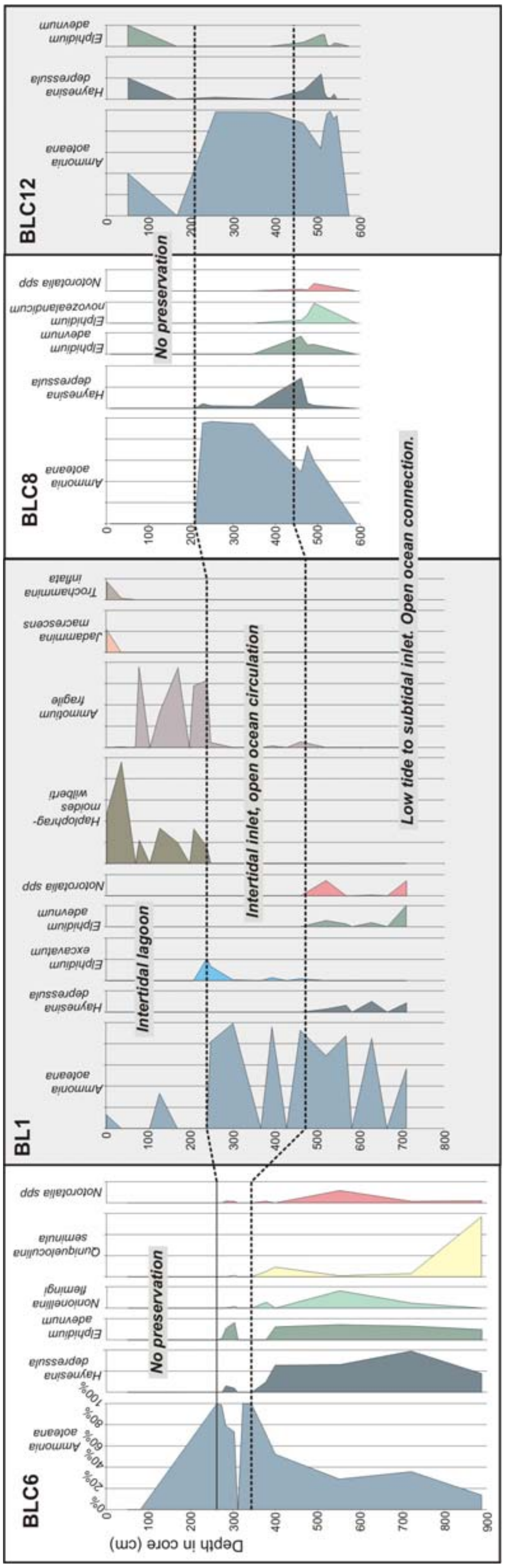


Figure 4 Foraminifera assemblages of the Big Lagoon cores. A general environmental trend from open ocean, subtidal water to enclosed, shallow intertidal water can be seen up through the cores. Full foraminifera census counts are in Appendix 1. The depth scale is in centimetres. Each column represents 20% of the total assemblage.

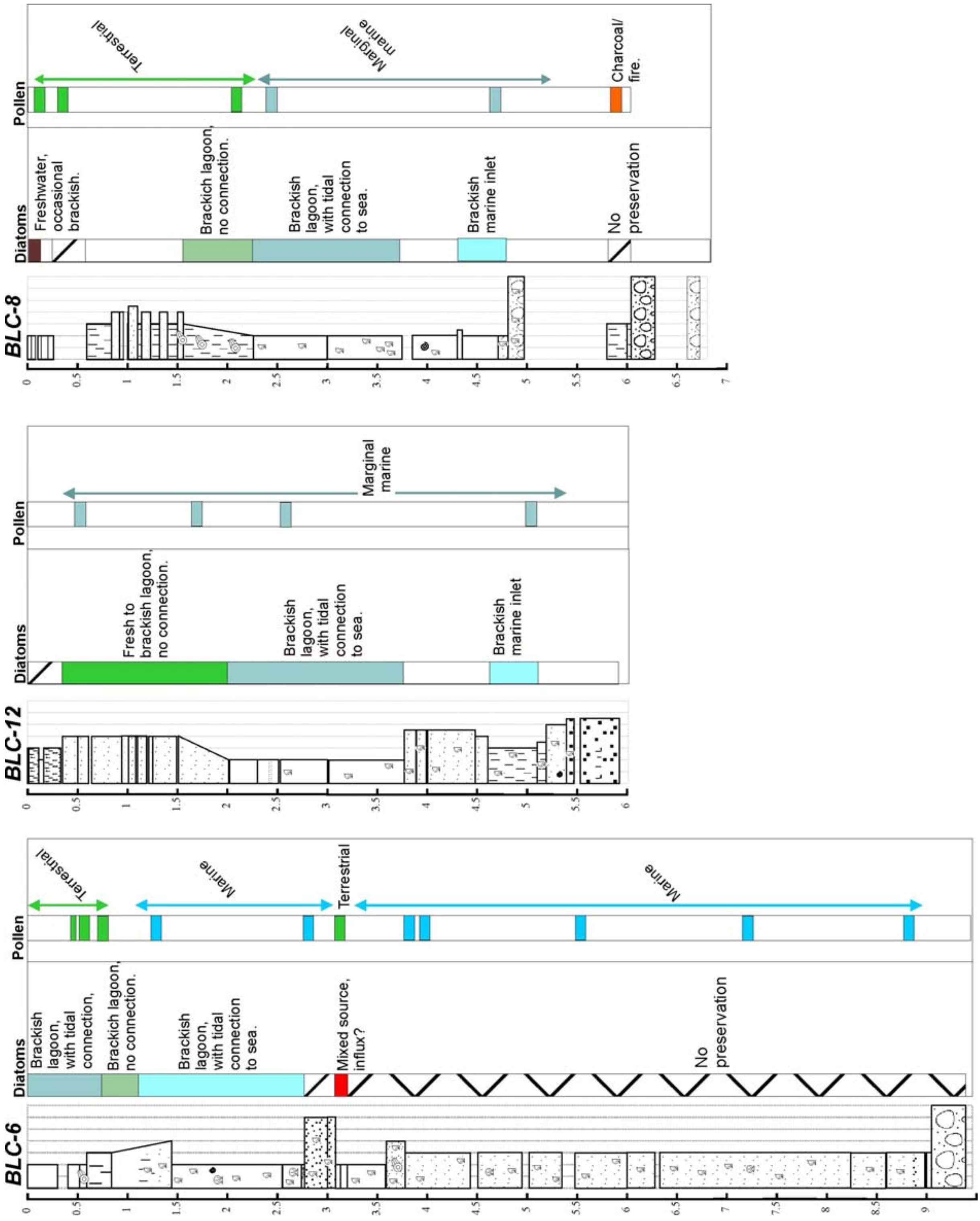


Figure 5 Summarised results of the diatom and palynology analyses from BLC6, BLC8, and BLC12. See Appendix 2 (this report) for the full diatom results and Appendix 3 of the 2006-07 PSR Task progress report (Cochran and Wilson, 2007) for the full pollen results. The depth scale is in metres.

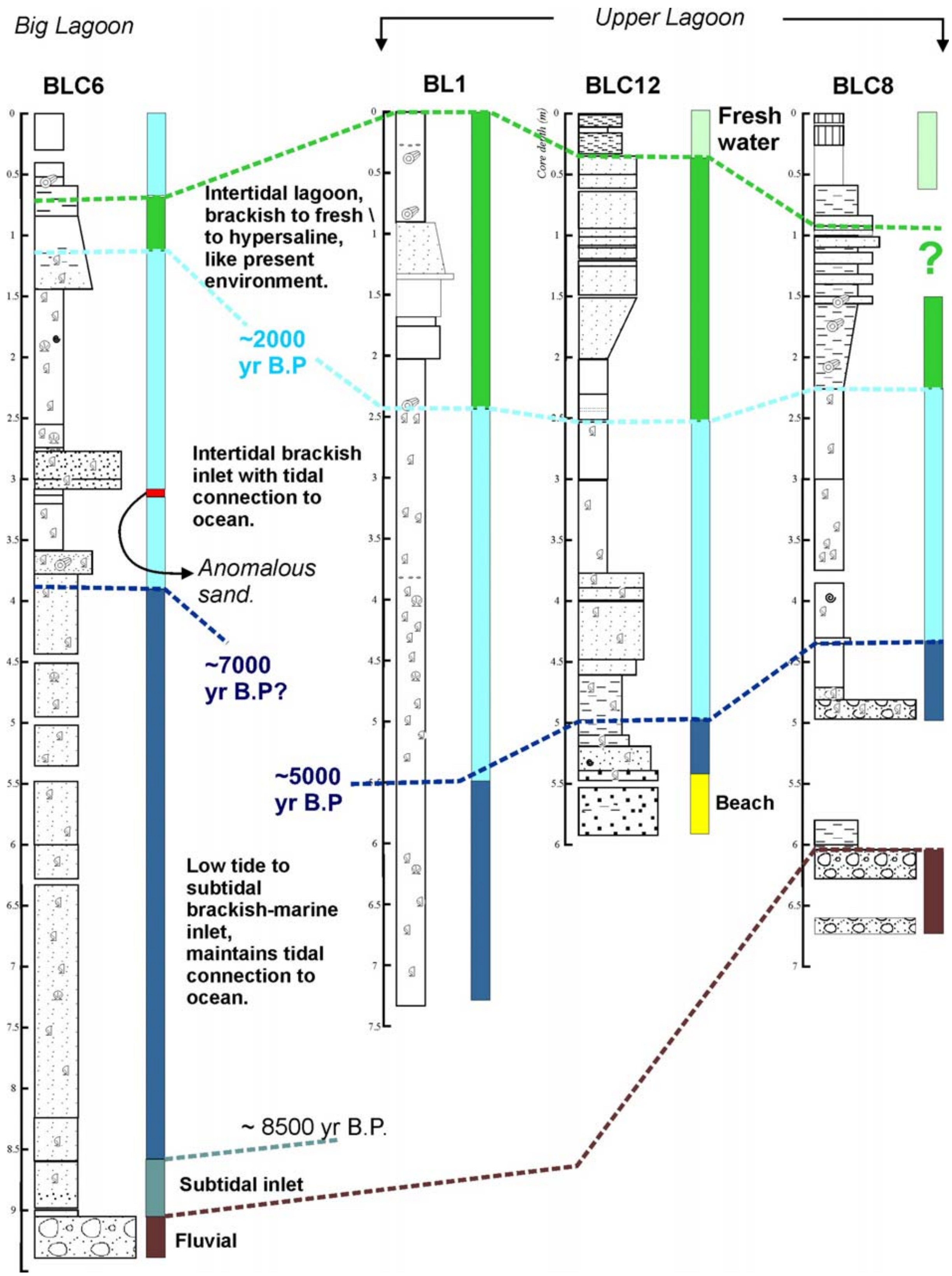


Figure 6 Summary diagram of the paleoenvironmental evolution of Big Lagoon and Upper Lagoon. The depth scale is in metres.

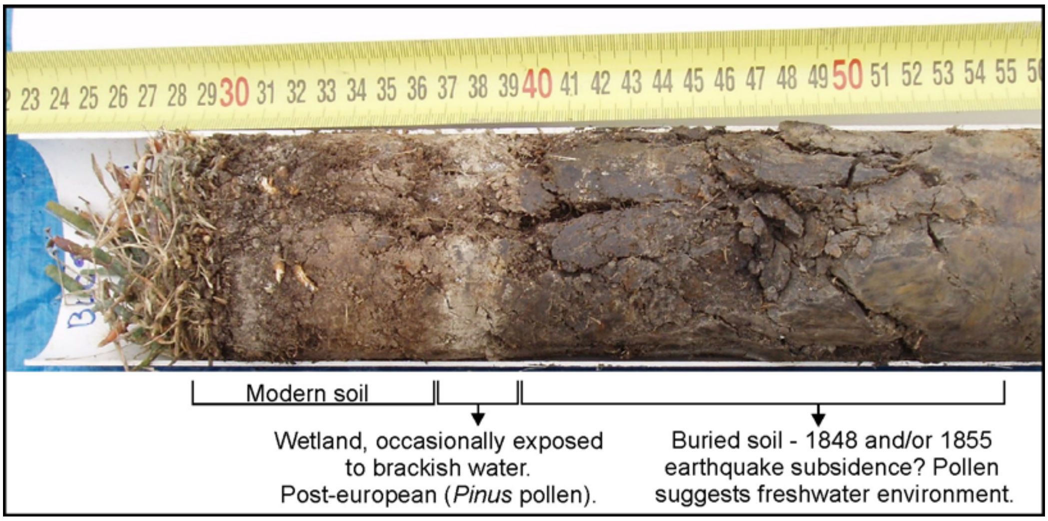


Figure 7 Upper 25 cm of BLC8 showing the buried soil that may represent subsidence in the 1848 or 1855 earthquakes or a relative SL change due to human alteration of the drainage.

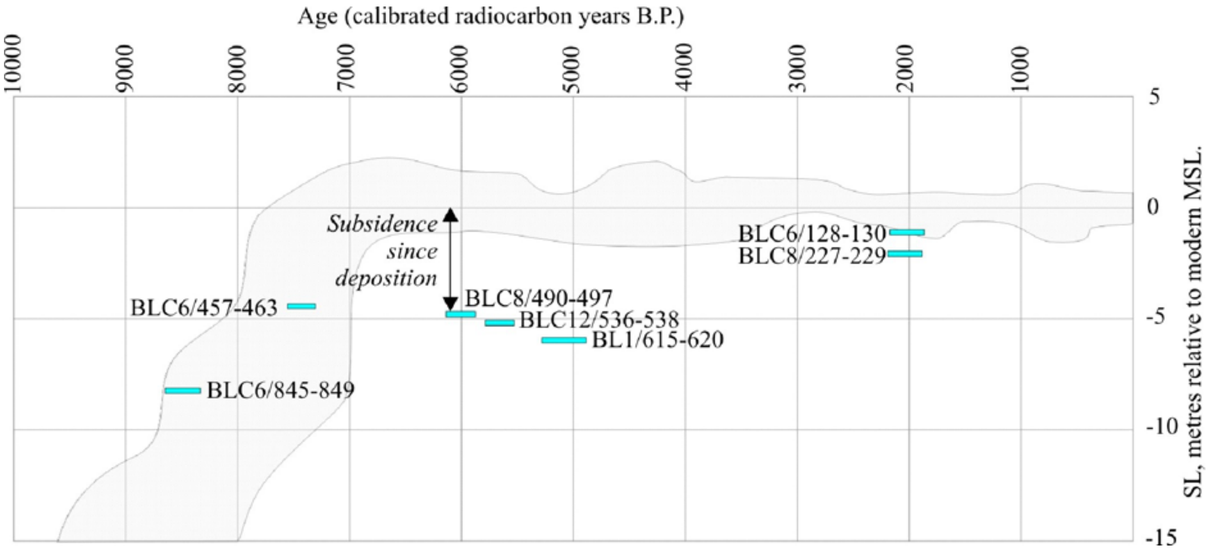


Figure 8 Radiocarbon ages and depths (blue rectangles) from the Big Lagoon cores plotted against the New Zealand regional sea level curve (grey shading, Gibb, 1986).

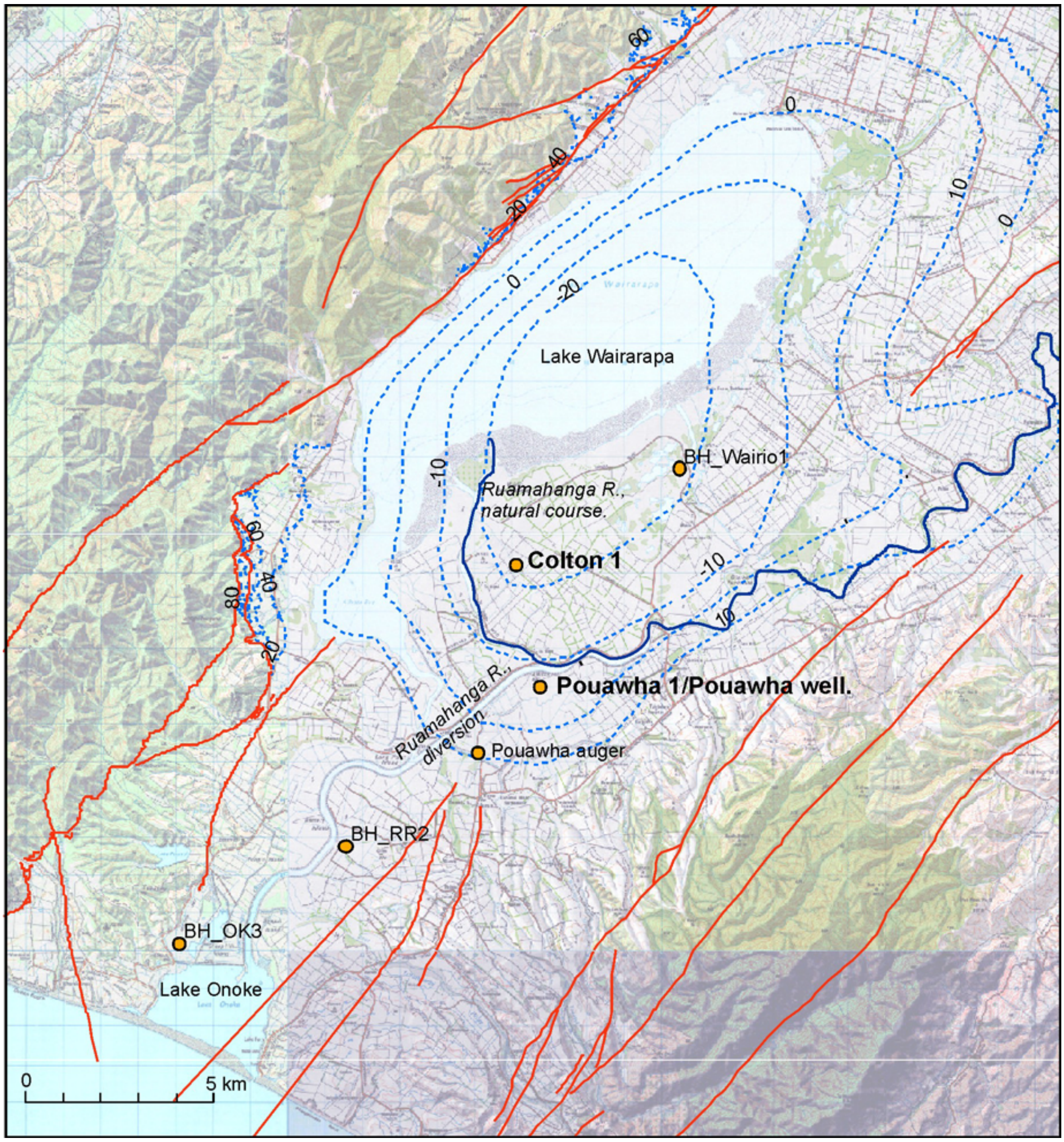


Figure 9 Topographic map of the Lake Wairarapa region, also shows the location of drill cores collected in the 07-08 field season. Shown in red are active faults from the GNS Active Faults Database. Blue dashed contours show estimates of the top of the last glacial gravel surface, contours were constructed by John Begg based on the extrapolation of topographic contours of the surrounding Q2 gravel surfaces.

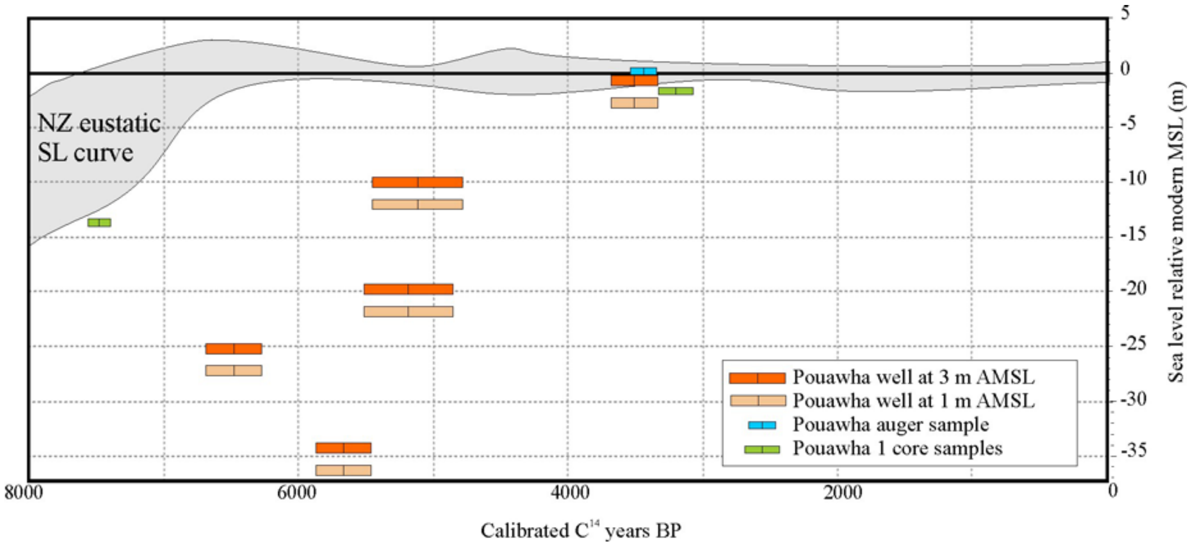


Figure 10 Radiocarbon ages and depths of estuarine shells obtained from the Pouawha well, Pouawha auger and Pouawha 1 core. See Table 1 for radiocarbon sample details and Figure 9 for locations. Also shown is the New Zealand regional sea level curve (grey shading, Gibb, 1986).

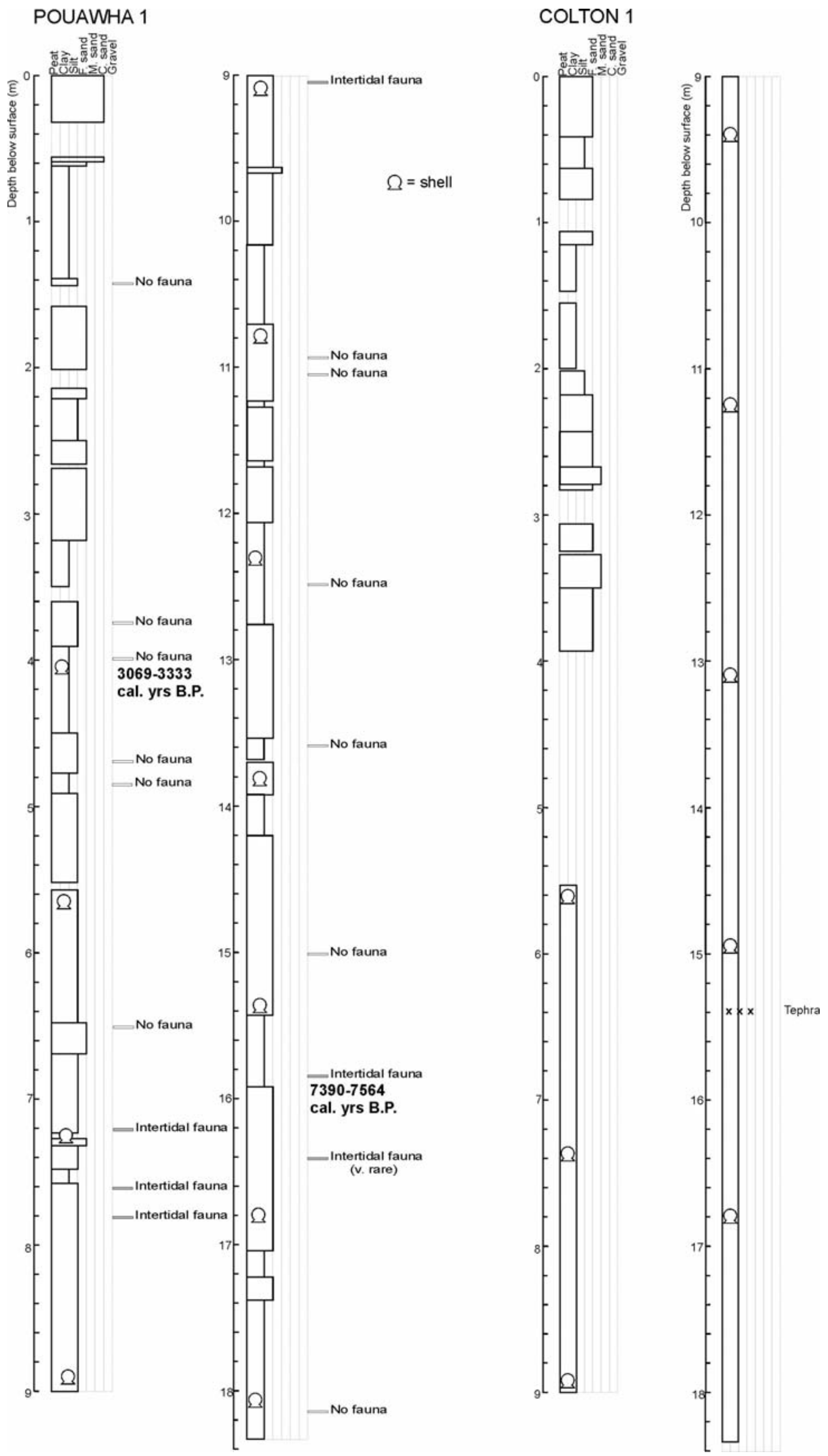


Figure 11 Simplified stratigraphic logs of the Pouawha 1 and Colton 1 cores. Also shown are the locations of foraminifera samples and radiocarbon ages in Pouawha 1.

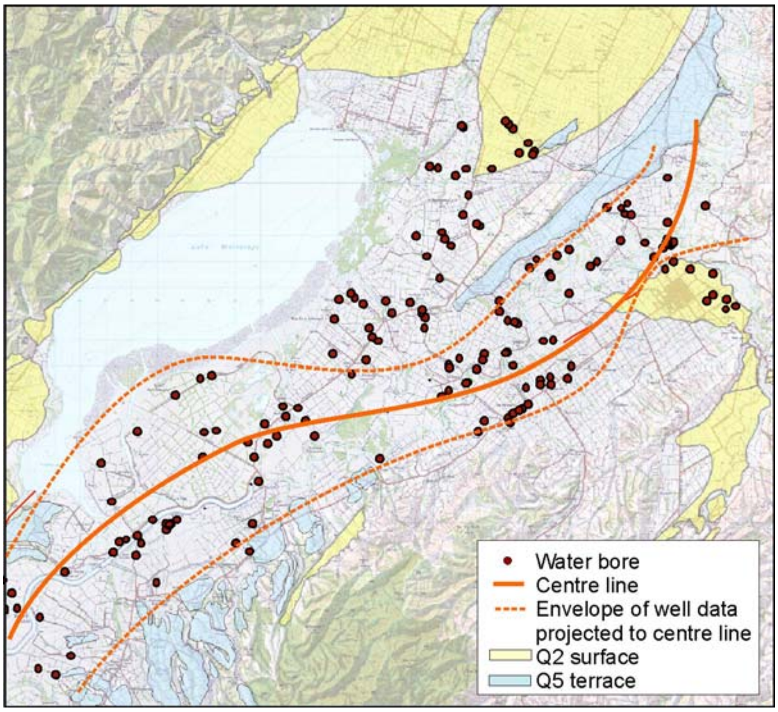


Figure 12 Water bore locations of the lower Wairarapa Valley (shown as red dots). The solid orange line shows the line onto which we projected the well bore data (results shown in Figure 13). Well data projected to the solid orange line was only from the wells located within area enveloped by the dashed-orange lines. Also shown are the Q2 and Q5 surfaces after Begg and Johnston, 2000.

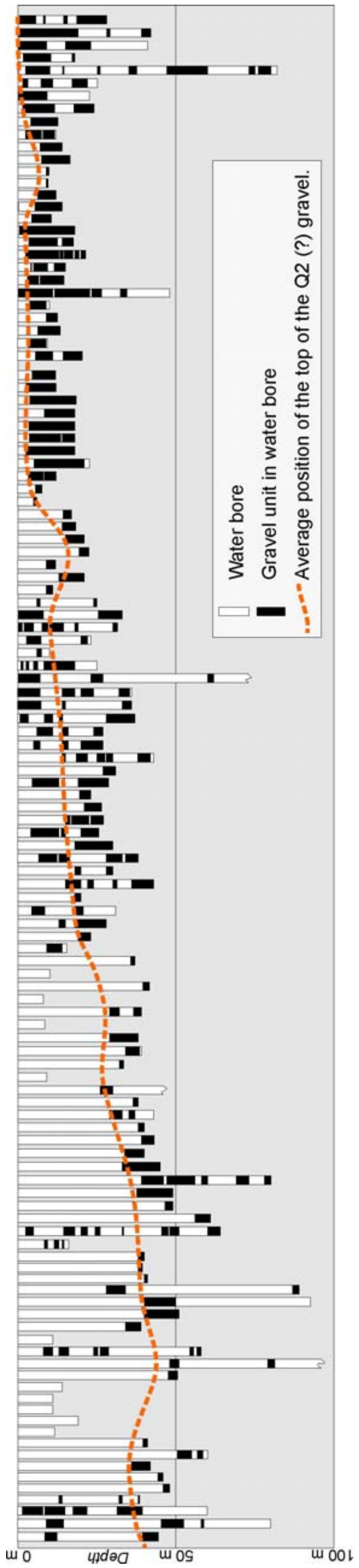


Figure 13 Preliminary mapping of the estimated Q2 gravels beneath the lower Wairarapa Valley. Top of the cores have not been corrected for elevation. Location of the drill holes and projection lines are shown in Figure 13.

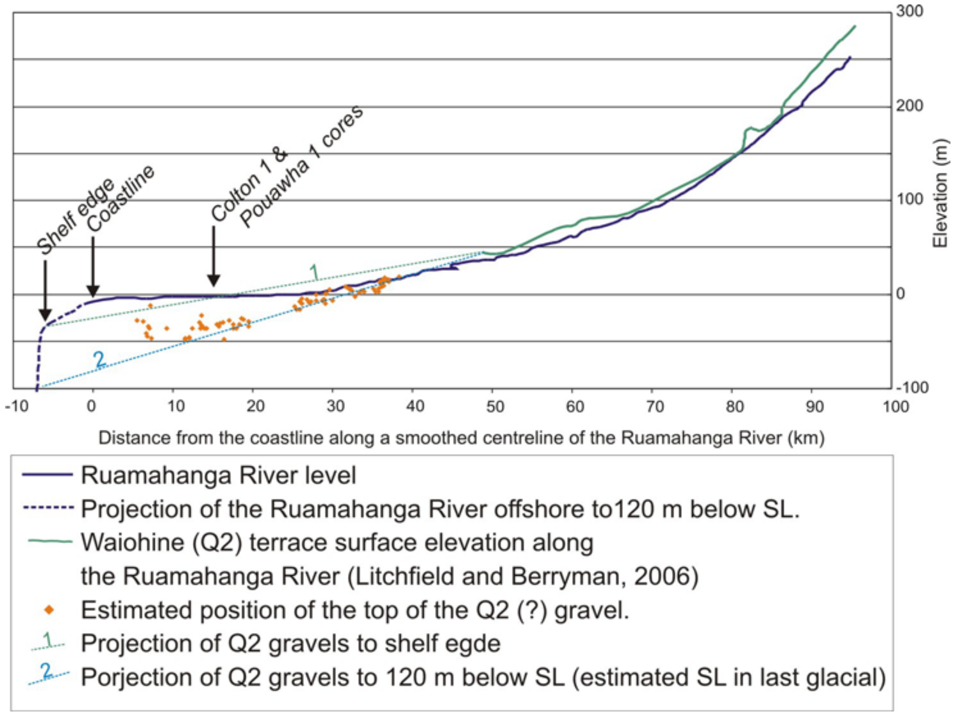


Figure 14 Preliminary graph showing the estimated depths of the Q2 gravels in the lower Wairarapa Valley compared with known data on the elevation of the Waiohine (Q2) surface upriver and projections of the Q2 gravels elevations during the last glacial period. We show two projections of the Q2 surface: (1) if the Ruamahanga River base level in the last glacial was at the shelf edge, (2) if the Ruamahanga River base level in the last glacial was at the 120 m bathymetric contour (-120 m being the estimated position of SL during the last glacial maximum).

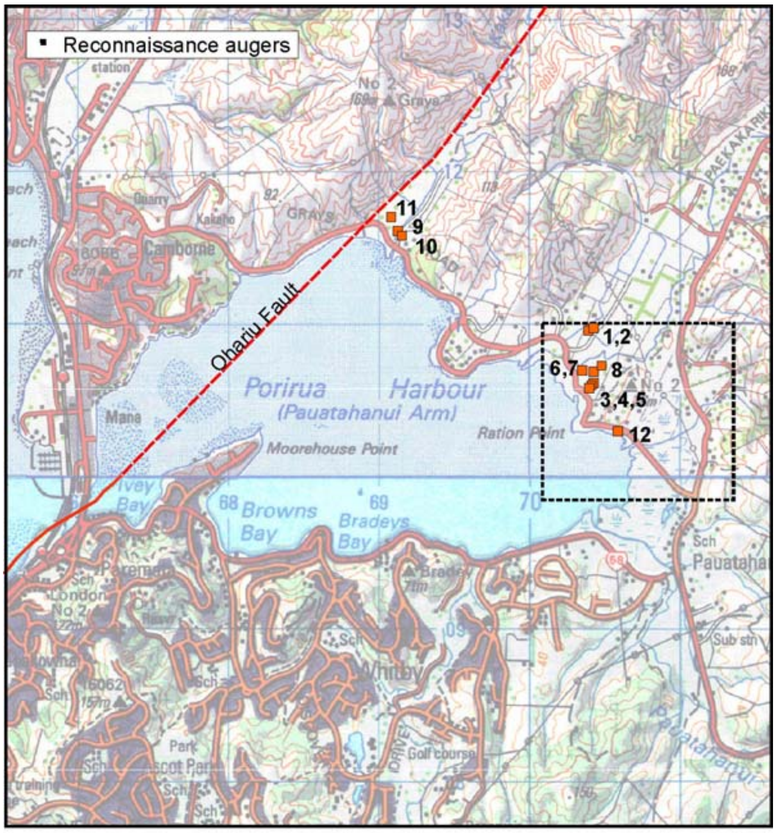


Figure 15 Upper figure shows a topographic map of the Pauatahanui Inlet with the location of the Ohariu Fault and the augers obtained during reconnaissance field work (dashed box shows the area enlarged below). Lower figure shows an aerial photo of the northeastern part of Pauatahanui Inlet and the locations of the cores and probes obtained for this study in February 2008.

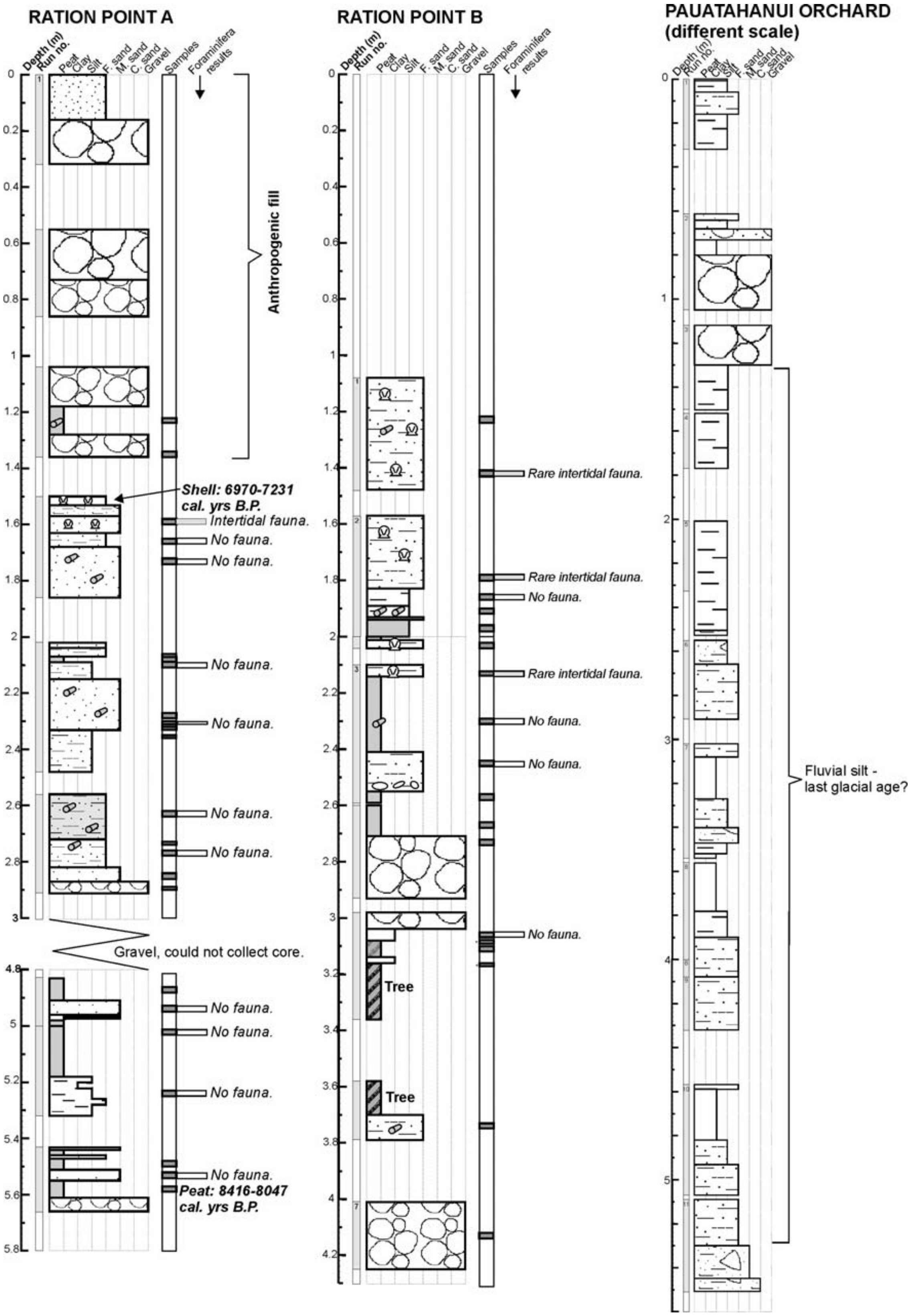


Figure 16 Stratigraphic logs of the Pauatahanui Inlet cores: Ration Point A, Ration Point B and Pauatahanui Orchard. Some preliminary paleoenvironmental data is shown (full foraminifera data is in Appendix 5), and the locations of two radiocarbon samples.

Figure 17 Photos from the drilling at Pauatahanui Inlet. Lefthand photo shows alternating peat and sand units in the Ration Point A core at 4.83 to 5.32 m depth. Centre photo shows the drill truck near the margins of Pauatahanui Inlet while collecting the Ration Point B core. Right hand photo shows the stiff, weathered gritty silt of the Pauatahanui Orchard core between 4.57 and 5.06 m depth.

TABLE

Table 1 Radiocarbon ages obtained from the lower Wairarapa valley and Pauatahanui Inlet cores.

Core	**Depth**	**Description**	**NZA**	**R Number**	**Radiocarbon age (B.P)**	**Calibrated age, yrs B.P., 2-sigma uncertainty**
Pouawha 1	3.98-4	*P. australis* fragments	*29685*	29832/1	3310 +/- 40	3069-3333
	10.24-10.26	*A. stutchburyi* fragments	*Submitted*			
	15.84-15.86	*A. stutchburyi* fragments	*29686*	29832/2	6931 +/- 45	7390-7564
Colton 1	6.74	*P. australis* fragments	*Submitted*			
	15.92-15.94	*A. stutchburyi* fragments	*Submitted*			
Ration Point A	1.56-1.6	*A. stutchburyi* fragments	*29687*	29832/3	6547 +/- 45	6970-7231
	5.57-5.59	Peat, clayey with some macro-plant fragments.	29752	29832/4	7521 +/- 85	8416-8047

APPENDICES

APPENDIX 1 FORAMINIFERA CENSUS FROM THE BIG LAGOON CORES.

Core	Sample	Ammonia aoteana	Haynesina depressula	Elphidium excavatum	Elphidium adevnum	Elphidium novozealandicum	Nonionellina flemingi	Notorotalia finlayi	Quniqueloculina seminula	Notorotalia inornata	Notorotalia spp	Pileolina zealandica	Bolivina subexcavata	Bolivina neocompacta	Bolivina cocazela	Fissurina claricurta	Haplophragmoides wilberti	jadammina macrescens	miliammina fusca	Bolivina striatula	Ammotium fragile	Quinqueloculina spp.	Saidovina karreriana	Trochammina inflata	Trochamminita salsa	Evolvocassidulina orientalis	Other	Total	Fraction Picked	Dry wgt	Wgt >63um	Abundance per g sediment	Abundance per g sand	% Sand
BLC6	49-51																											0	1/2	28.1	0.4	0	0	1%
BLC6	55-57																											0	1	17.7	0.2	0	0	1%
BLC6	80-82																											0	1/16	59.1	8.6	0	0	15%
BLC6	139-141	12																										12	1/16	33.3	14.4	6	13	43%
BLC6	260-262	440	1																									441	1/8	32.0	1.1	110	3267	3%
BLC6	272-274	392			5																						1	398	1/2	24.7	0.2	32	4422	1%
BLC6	282-284	262	20		36	7	1	6																				332	1/64	74.5	57.1	285	372	77%
BLC6	302-304	157	8		35	4	3		3		3			1														214	1/64	52.8	38.1	259	360	72%
BLC6	310-312																											0	1	38.5	0.7	0	0	2%
BLC6	322-324	117																										117	1	61.8	1.8	2	65	3%
BLC6	342-344	284																									1	285	2/7	32.8	0.3	30	3117	1%
BLC6	376-378	91	12			2	7	2	6			1	1		1												4	127	3/128	49.3	25.9	110	209	53%
BLC6	398-400	51	25		12	1			9																			98	5/64	34.7	18.6	36	68	53%
BLC6	551-553	32	29		16	1	18		1		13					1												111	3/16	41.0	5.7	14	104	14%
BLC6	720-722	47	51		17		6		4		2		1														3	131	1/16	47.5	22.8	44	92	48%
BLC6	886-888	7	9		5			1	29																			51	1/8	42.6	24.7	10	16	58%
BLC8	8-10																											0	1	16.3	0.3	0	0	2%
BLC8	30-32																											0	1	37.6	0.4	0	0	1%
BLC8	104-106																											0	1/32	28.7	26.4	0	0	92%
BLC8	208-210																											0	1	23.5	0.1	0	0	1%
BLC8	227-229	371	17	2																								390	1/4	44.6	0.4	35	3900	1%
BLC8	248-250	389	10																								4	403	1/8	50.0	1.9	65	1733	4%
BLC8	346-348	308	6	12																								326	1/16	60.0	7.7	87	682	13%
BLC8	460-462	161	94	1	55	9				1	4																3	328	1/4	30.0	0.2	44	7289	1%
BLC8	475-477	256	18		30	28			2		3																11	348	1/32	47.8	31.4	233	355	66%
BLC8	490-495	161	8		25	52			4		19																5	274	1/128	144.6	116.8	243	300	81%
BLC8	590-592																											0	1/32	51.9	4.9	0	0	9%

Core	Sample	Ammonia aoteana	Haynesina depressula	Elphidium excavatum	Elphidium advenum	Elphidium novozealandicum	Nonionellina flemingi	Notorotalia finlayi	Quniqueloculina seminula	Notorotalia inornata	Notorotalia spp	Pileolina zealandica	Bolivina subexcavata	Bolivina neocompacta	Bolivina cocazela	Fissurina claricurta	Haplophragmoides wilberti	jadammina macrescens	miliammina fusca	Bolivina striatula	Ammotium fragile	Quinqueloculina spp.	Saidovina karreriana	Trochammina inflata	Trochamminita salsa	Evolvocassidulina orientalis	Other	Total	Fraction Picked	Dry wgt	Wgt >63um	Abundance per g sediment	Abundance per g sand	% Sand
BLC12	50-52	2	1		1						1																	5	1/4	31.0	7.9	1	3	25%
BLC12	166-168																											0	1/64	32.8	23.2	0	0	71%
BLC12	257-259	161	3																									164	1/8	45.4	5.3	29	248	12%
BLC12	383-385	224		5																								229	1/16	37.3	22.4	98	164	60%
BLC12	464-466	157	15		7																							179	1/16	33.5	7.2	85	399	21%
BLC12	506-508	138	52		24		1				1																1	217	1/16	40.0	2.8	87	1258	7%
BLC12	514-516	117	8		16																							141	1/32	40.4	11.4	112	394	28%
BLC12	521-523	262	4		4																						2	272	1/32	52.8	31.8	165	274	60%
BLC12	528-230	201	2																									203	3/128	64.0	46.4	135	187	72%
BLC12	536-538	149	8		5																							162	1/64	53.5	40.3	194	257	75%
BLC12	544-546	124			4	1			1																		1	131	3/32	34.3	32.0	41	44	93%
BLC12	573-575								1																			1	1/32	26.0	25.1	1	1	96%
BL1	0-2	3															11	5						4				23	1	56.9	0.3	0	77	1%
BL1	35-37																130		2		1			2	1			136	1/4	51.0	0.5	11	1088	1%
BL1	68-70																											0	0	51.7	1.2	0	0	2%
BL1	77-79																21		2		72							95	1/32	50.7	1.6	60	1854	3%
BL1	102-104																											0	0	54.7	3.5	0	0	6%
BL1	126-128	1															1				1							3	1	61.8	29.1	0	0	47%
BL1	168-170																23		7		88							118	1/4	44.0	0.4	11	1311	1%
BL1	196-198																											0	0	50.0	0.8	0	0	2%
BL1	206-208																36		10		64				1			111	1/16	43.8	0.3	41	5920	1%
BL1	237-239			30													22		1		90							143	1/4	34.6	0.5	17	1144	1%
BL1	246-248	85		14																	5							104	1/8	46.3	0.5	18	1664	1%
BL1	299-301	128		1																								129	1/4	50.4	0.0	10	51600	0%
BL1	365-367																											0	0	48.0	0.2	0	0	0%
BL1	391-393	137		4																	2							143	1/4	47.0	0.6	12	1021	1%
BL1	426-428																											0	0	47.1	2.3	0	0	5%
BL1	459-461	102		2																	6							110	1/16	53.9	1.2	33	1504	2%
BL1	519-521	71	3		6		4				15		1							1		1	1			1		104	1/8	50.6	0.1	16	16640	0%
BL1	567-569	137	10		4		3						1									1						156	1/16	51.6	0.8	48	3081	2%
BL1	580-582																											0	0	50.2	0.8	0	0	2%
BL1	627-629	109	13		5						1																	128	1/16	51.6	0.4	40	4876	1%
BL1	664-666																											0	0	50.4	0.5	0	0	1%
BL1	709-711	83	13		30						21																	147	1/8	52.1	0.2	23	5345	0%

APPENDIX 2 DIATOM RESULTS FROM BIG LAGOON CORES, BLC6, BLC8 AND BLC 12

DIATOM RESULTS FOR BIG LAGOON CORE 6

Sample	Preservation	Concentration	Dominant Salinity-Habitat Preferences	Additional Features	Environment
49-51	Good	High	Brackish & indifferent species of benthic habitats	Soil diatoms present + brackish marine forms (eg, 10% *Paralia sulcata*)	Shallow brackish lagoon with connection to the sea or influx of brackish marine species
55-57	Good	High	Brackish & indifferent species of benthic habitats	Soil diatoms present	Shallow brackish lagoon with no direct marine connection
80-82	Good	High	Brackish marine & brackish species of benthic habitats		Lagoon with tidal connection to the sea
139-141	Good	Moderate	Brackish marine species of benthic habitats		Lagoon with tidal connection to the sea
282-284	None preserved				
310-312	Good	Moderate	Brackish, fresh & indifferent species of benthic & tychoplanktic habitats	Assemblage indicative of transitional, fluctuating conditions or mixed sources	Fresh-brackish lagoon with no direct marine connection or an influx event
376-378	None preserved				
398-400	None preserved				
551-553	None preserved				
720-722	None preserved				
886-888	None preserved				

Comments:

Analysis of further samples around the transition at 55-57 cm would be worthwhile to determine whether the environment became more marine above this sample or whether there was a short-lived brackish marine influx.

Analysis of further samples around the transition at 310-312 cm would be worthwhile to determine whether the fresh-brackish unit is an influx event or a longer-lived phase in the lagoon's history.

DIATOM RESULTS FOR BIG LAGOON CORE 12

Sample	Preservation	Concentration	Salinity-Habitat	Additional Features	Environment
50-52	None preserved				
166-168	Good	Moderate	Fresh & indifferent species of benthic & tychoplanktic habitats	Occasional brackish species present	Shallow fresh to fresh-brackish lagoon with no direct marine connection
257-259	Good	High	Brackish marine & indifferent species of benthic & tychoplanktic habitats		Shallow brackish marine lagoon with tidal connection to the sea
506-508	Good	Moderate	Brackish marine species of benthic & planktonic habitats	Occasional fresh and soil diatoms present	Brackish marine inlet

Comments:

Analysis of further samples in the upper 30 cm would be worthwhile to determine whether the transition that occurs in BLC-6 also occurs in BLC-12.

Analysis of further samples around 200 cm could be useful for determining how sudden the marine to freshwater transition is (and thereby what the likely cause was).

DIATOM RESULTS FOR BIG LAGOON CORE 8

Sample	Preservation	Concentration	Salinity-Habitat	Additional Features	Environment
8-10 cm	Good	Moderate	Fresh species of moist soil habitats	Occasional brackish species	Freshwater wetland / soil environment occasionally exposed to brackish water
30-32	None preserved				
209-211	Good	Very high	Brackish & indifferent species of benthic & tychoplanktic habitats	Occasional fresh and brackish marine species	Shallow brackish lagoon with no direct marine connection
248-250	Good	High	Brackish marine, brackish & indifferent species of benthic & tycho. habitats		Shallow brackish lagoon with tidal connection to the sea
460-462	Good	Moderate	Brackish marine & brackish species of benthic, tycho. & planktic habitats		Brackish marine inlet
590-592	None preserved				

Comments:

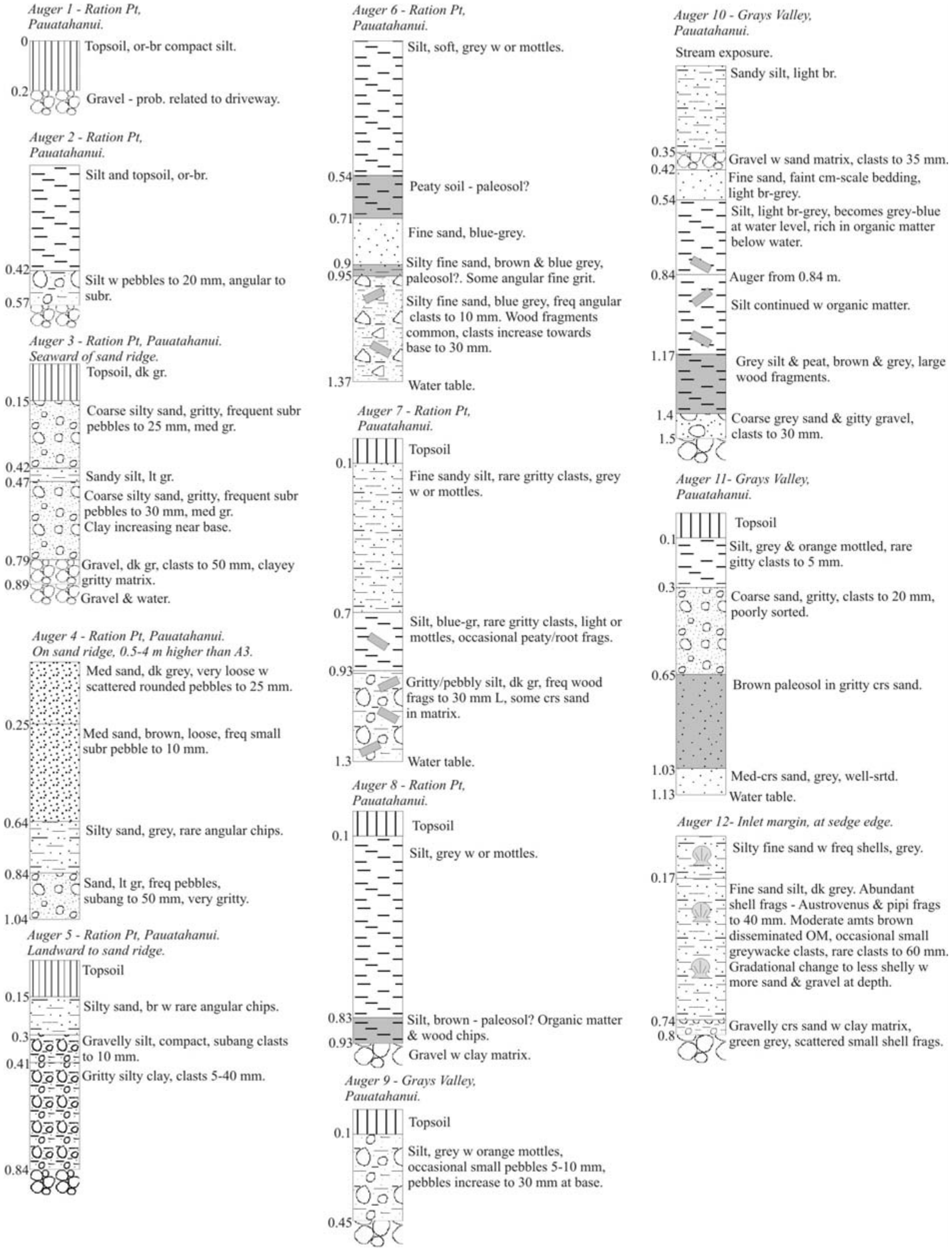
Analysis of further samples in the upper 30 cm would be worthwhile to determine whether the transition that occurs in BLC-6 also occurs in BLC-8.

Analysis of further samples around 230 cm could be useful for determining how sudden the environmental transition is at that position.

APPENDIX 3 POUAWHA 1 FORAMINIFERA CENSUS

	Sample depth (m)	**Ammonia aoteana**	**Elphidium excavatum**	**Notorotalia spp**	**Ammotium fragile**	**Other**	**Total**	Fraction Picked	Dry wgt	Wgt >63um	Abundance per g sediment	Abundance per g sand	% Sand	Macro shell fragments	Organic matter	Other
1.42	1.43						0	1/16	24.05	10.75	0	0	45%	No.	Very rare OM.	No marine indicators, medium grain sand.
3.74	3.76						0	1	26.36	0.09	0	0	0%	No.	Small amount OM.	Few mineral grains.
3.98	4				1		1	1	12.74	0.02	0.08	50	0%	Rare & small shell frags < 2mm.	Small amount OM	V fine grained sample.
4.68	4.7						0	1	20.8	0.01	0	0	0%	No.	Mostly micro OM.	No marine indicators, few mineral grains.
4.83	4.87	1					1	1	21.06	0.25	0.05	4	1%	Many small (<2mm) frags, possibly P. austral.	Large amount OM.	V little mineral material.
6.5	6.52						0	1	16.17	0.61	0	0	4%	No.	Moderate amount OM.	No marine indicators, mostly fie sand.
7.2	7.23	123	6				129	1/8	40.71	6.5	25.4	158.77	16%	Abundant shell frags, A. stutch frags to 20 mm L & whole juvs, P. austral frags to 20 mmL.	Mod amount OM.	
7.6	7.62	54					54	1	13.83	0.01	3.9	5400	0%	Scattered micromolluscs, potamopyrgus.	Small amount OM.	V little mineral matter.
7.8	7.82	37					37	1	18.6	0.01	1.99	3700	0%	No.	Large amount OM.	Few mineral grains.
9.04	9.055	4	11			24	39	1	11.61	0.42	3.36	92.857	4%	Common micrmolluscs, all potamopyrgus.	rare OM.	Mostly fine mineral grains.
10.92	10.94						0	1	14.64	0.01	0	0	0%	No.	Mostly OM.	No marine indicators, very little OM.
11.04	11.06						0	1	17.22	0.04	0	0	0%	No.	Moderate amount OM.	No marine indicators.
12.48	12.5						0	1	21.02	0.01	0	0	0%	No.	Small amount micro-OM.	No marine indicators & v litte mineral material.
13.58	13.6						0	1	27.29	0.26	0	0	1%	Rare & small degraded shell frags, < 3 mm L.	Moderate amount OM.	
15	15.02						0	1	17.41	0.01	0	0	0%	No.	Large amount (~50%) OM.	Vfine gr sample, little sediment.
15.84	15.86	137					137	1/16	24.32	2.38	90.1	921.01	10%	Fragments of A. stutch to 10 mm L, some juv shells.	Mode amount OM.	Forams clear & well preserved.
16.4	16.42	4		2			6	1	26.8	1.4	0.22	4.2857	5%	No.	Medium amount OM.	All forams degraded/fragmented.
18.13	18.15						0	1	20.22	0.01	0	0	0%	No.	Mostly micro OM.	No marine indicators, few mineral grains.

APPENDIX 4 AUGER STRATIGRAPHY COLLECTED DURING RECONNAISSANCE FIELD WORK OF PAUATAHANUI INLET, NOVEMBER 2007.



APPENDIX 5 FORAMINIFERA CENSUS OF SAMPLES FROM THE RATION POINT A AND RATION POINT B CORES.

	Sample depth (m)	*Ammonia aoteana*	*Elphidium excavatum*	Total	Fraction Picked	Dry wgt	Wgt >63um	Abundance per g sediment	Abundance per g sand	% Sand	Macro shell fragments	Organic matter	Other
Ration Point A													
1.58	1.6	86		86	1/4	19.53	8.02			41%	A. stutch fragments to	Moderate amount OM.	
1.65	1.67			0	1/8	19.5	6.03	0	0	31%	Small, <3mmL, shell		
1.72	1.74			0	1/8	28.83	14.27	0	0	49%	-	Moderate amount OM.	No marine ind, mostly fine-med sand with some crs granules to 8
2.09	2.11			0	1	9.33	0.81	0	0	9%	-	moderate amount OM.	No marine indicators, mostly fine mineral grains.
2.3	2.31			0	1/4	6.72	1.67	0	0	25%	-	Moderate amount OM.	No marine indicators.
2.62	2.64			0	1/8	25.58	8.6	0	0	34%		Moderate amount OM.	No marine ind, mostly fine sand.
2.76	2.78			0	1/16	34.08	20.61	0	0	60%	-	Rare OM.	No marine indicators, med-fine sand.
4.93	4.95			0	1/8	14.39	9.02	0	0	63%	-	Rare OM.	No marine indicators, mostly med gr sand.
5.01	5.03			0	1/4	11.24	3.56	0	0	32%		Moderate amount OM.	No marine ind, medium-fine sand.
5.23	5.25			0	1/16	16.48	3.54	0	0	21%	-	Small amount micro-OM.	Barren, no marine indicators, mostly mineral grains.
5.52	5.54			0	1/16	17.59	13.58	0	0	77%	-	-	No marine indicators, small rounded clasts to 10 mm diam, v crs & poorly srtd sand.
Ration Point B													
1.41	1.43	26		26	1/4	25.44	11.89	4.0881	8.7468	47%	Scattered shell frags to 7	Small amount OM.	Forams v rare.
1.78	1.8	25		25	1	10.32	1.9	2.4225	13.158	18%	Shell frags to 8 mmL.	Moderate amount OM.	Forams poorly preserved, white, fragmented shells.
1.85	1.87			0	1/4	11.46	1.61	0	0	14%	Abraded shell frags to 5	Moderate amount OM.	
2.12	2.14	74	1	75	1/2	16.46	2.95	9.113	50.847	18%	Occasional small ,10mmL	Large amount OM.	Forams v rare.
2.29	2.31			0	1	7.39	0.36	0	0	5%	-	Moderate amount OM.	No marine ind.
2.44	2.46			0	1/8	11.99	2.53	0	0	21%	-	Large amount OM.	No marine ind.
3.05	3.07			0	1/8	38.76	4.1	0	0	11%	-	Moderate amount OM.	No marine ind.

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