Disturbance in the North Island of New Zealand: A case study using floodplain cores from the Coromandel to determine anthropogenic disturbance

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in Geography

Massey University, New Zealand

Elizabeth Grace Fox

2016

Kuaotunu Stream with the surrounding Kuaotunu floodplain.

Photographer E.Fox, 25-03-2014.

Table of Contents

List of Figures

List of Tables

Abstract

It is well documented that following human occupation of a region, the surrounding environment may undergo drastic changes through vegetation pattern alterations, displacement of fauna, alteration of sedimentation and fluvial regimes, and changes to the composition of the underlying material. Many case studies of anthropogenic disturbance have been conducted in New Zealand. One of the main outcomes of this research is to collate, contrast and compare this wealth of case studies to look for any underlying trends in timing, distribution and magnitude of disturbance nationwide. This thesis focusses on late Holocene records from the North Island, and compared the history of disturbance with that from the South Island (as per McWethy et al. 2010). Based on the combination of palynology, sedimentology and geochemistry, this review demonstrates the pace of disturbance observed in the North Island was very rapid following occupation, a trend also established in the South Island.

The other main outcome of this research is to add to the knowledge base of North Island disturbance history, through development of a landscape disturbance history in the Coromandel, using floodplain cores from the Paeroa and Kuaotunu areas. Sediment logging and subsequent XRF-geochemical analysis performed on these cores revealed a 'mining layer' that was used as a baseline for mining disturbance in this environment. This layer is interpreted as when European activities began disturbing the environment. Cores extracted from the Paeroa area indicated that the sedimentation rates in the floodplain had increased more than 15-fold since human occupation. Significant rises in the amount of Arsenic and Lead contained within the sediment were also detected. Cores from the Kuaotunu floodplain also showed changes in geochemistry that coincided with historic mining in the area, but reverted back to near pre-mining levels following the initial disturbance. These results suggest that factors such as catchment characteristics and degree of disturbance in an area affect the extent of impact on a site, which may have implications for future management of post mining sites. XRF analysis is a relatively underutilized proxy in New Zealand. It, in conjunction with Particle Size Analysis, has proved valuable in this study and

are recommended for application in future New Zealand environmental reconstruction-focused research.

Acknowledgements

Dr. I. Fuller, Dr. A. Clement and Dr. K. Holt for their support and advice with identifying sediment layers, geochemistry interpretation and assistance with coring and logging the floodplain cores. A big thank you to Mr. D. Feek for his assistance in the field and Dr. A. Moebis for her help with the processing of the subsamples and the use of the Particle Laser Scanner. A special thank you to Dr. T. Novakova at Aberystwyth University for carrying out the XRF NITON scanning to deduce the geochemistry of the Coromandel Cores and provision of these results.

A special thank you to Mr. B Watson, Mr J. Watson and Mrs M. Rose at Horizons Regional Council for their enthusiasm, support and encouragement in the undertaking of this thesis.

And finally a huge thank you to my family and friends for their continued support and motivation they gave me throughout this project.

Chapter 1: Introduction

1.1 General Introduction

In an ecological and geographical context, disturbance is described as 'any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability, or the physical environment.' (Pickett & White, 1985). Disturbance of the natural environment can be caused by natural events, such as fires, earthquakes and floods (Wilmshurst *et al.* 1999; Newnham *et al*. 2013). However for centuries now it has been recognised that following human occupation of an area and interaction with the surrounding environment has perhaps caused the most significant and widespread disturbance in recent (Holocene) time (Mildenhall, 1979; McGlone, 1983; McGlone & Wilmshurst, 1999; Xu, 2003; Sutton, 2008; Marquer *et al*. 2014).

Disturbance caused by human activities can take many forms. Deforestation, changes in intensity of land use and practices, introduction of new species and modifying the surface of the landscape are a few examples (Sutton, 2008; McWethy *et al*. 2010; Fuller *et al*. 2015). The severity and the duration of the disturbance and the extent of any subsequent rehabilitation will control how significantly modified the environment is in comparison to its pre-disturbed state (Pickett & White, 1985).

The rate at which disturbance has occurred has varied globally, with disturbance occurring at a moderate pace in Europe until the 19th century (e.g. Shennan, 2009) and significantly faster in island nations (e.g. Janet *et al*. 2006; Sutton, 2008). The recognition of the impact of humans through widespread environmental disturbance has, in part, led to proposals for a new geological era, termed the 'Anthropocene'. This time epoch began when human impacts began to overwhelm natural processes in the environment, initiated between approximately AD 1800 (Foley *et al*. 2013) to the mid-20th century (Waters *et al*. 2014). However, it is difficult to determine a specific start time for this epoch due to the variability and magnitude of disturbance triggered by human activities. Fuller *et al*. (2015)

differentiated between Polynesian and European disturbance in Northland, New Zealand, observing that anthropogenic alluviation began from c. AD 1300. This was further exacerbated by European impacts in the late 19th to 20th centuries, highlighting the difficulties of formally designating a single 'Anthropocene Age'.

Prior to arrival of Europeans to New Zealand, the activities of Polynesian settlers resulted in considerable disturbance. McWethy *et al.* (2010) synthesised and expanded upon research into Polynesian disturbance in the South Island, and concluded that rapid changes to the environment did follow human arrival in this region. While some studies have addressed disturbance in the North Island as a whole (e.g. Kershaw & Strickland, 1988; Wilmshurst, 1997; Elliot *et al*. 1997; Bussell, 1998), to date, there has not been a review comparable to that of McWethy et al (2010) for the North Island to compare, contrast and validate their conclusions against.

The majority of disturbance studies carried out in New Zealand have focused on changes in vegetation patterns, yet with new advances in technologies multiple other proxies can help to validate the previous works as well as reveal trends and patterns that may exist.

A growing issue worldwide is how best to manage environments that have been drastically changed due to anthropogenic impacts (Macklin *et al*. 1994; Hudson-Edwards *et al*. 1997; Knox, 2006), which fuels the need to understand when and how the environment was altered, and thus the need for studies into the history of disturbance. Many human activities impact upon the environment. One such activity is mining, which releases harmful chemicals that can become trapped within sediments, but is also associated with the indirect impact of deforestation to clear land for the mines and related activities, resulting in increased sedimentation and alterations to the fluvial system (Crecelius *et al*. 1975; Hudson-Edwards *et al*. 1994; Razo *et al*. 2004; Macklin *et al*. 2006; Sims & Francis, 2008).

This distinct impact of mining on the environment however, can provide a clear marker for the transition from pre- to post-disturbance. This in turn, helps identify where the 'baseline' (i.e. what the environment was like prior to human occupation) conditions are captured in sedimentary sequences. Such baselines provide a reference to work from in regards to assessing the magnitude of disturbance that occurred in an area, the speed of the change and the long term impacts. Using sedimentological and geochemistry results can therefore provide invaluable information on what the environment was truly like prior to settlement. This is turn provides information on how best to manage the landscape and potentially rehabilitate it back towards a similar state.

1.2 Purpose of Study

The purpose of this study was three-fold. The first aim is to review the available information on environmental change primarily in response to anthropogenic impacts in the North Island, New Zealand, to look for spatial and temporal patterns and variation caused by disturbance events. This was done by collating the results from previous studies that used proxies (e.g. pollen, sedimentology) to determine how and why disturbance occurred in the areas (if at all). The second aim was to add to the collection of information on North Island disturbance events by generating a new case study from sites in the Coromandel Peninsula situated in the North Island. Sites subject to historic mining were used to assess the nature and extent of this particular type of disturbance in the environment. Therefore these results were analysed along with the previous studies' conclusions on how the landscape has changed and whether disturbance was considered to have been rapid, moderate or slow. Thirdly, the proxies applied in this case study, specifically sedimentology and geochemistry, are also reviewed with respect to their usefulness in determining human impact over time in floodplain cores as this is a relatively underutilized methodology in New Zealand environmental reconstructions.

Chapter 2: Disturbance

2.1 Measuring Disturbance

Human population has increased, resulting in changing methodologies of land use to accommodate the growth over the Late Holocene period. This has resulted in significant modification to natural vegetation patterns, river systems and fauna distribution worldwide (McAndrews, 1988; Owens & Walling, 2002; Sutton *et* al. 2008; Marquer *et al* 2014). The impact of humans on the global environment has been tracked back in excess of 8,000 years (Ruddiman, 2003; Ruddiman *et al*. 2011), where fires by early civilizations caused rises in CO_2 emissions, along with wide spread replacement of vegetation with agricultural land. However there is much evidence which demonstrates that the greatest spatial and magnitude of disturbance has occurred in the last 2 centuries, giving rise to the Anthropocene (Brown *et al*. 2013; Fuller *et al*. 2015). This proposed epoch is characterised by a shift whereby humans are now the largest influence on the environmental systems operating on our earth.

While the fact that a given region has experienced anthropogenic disturbance is often very clear, understanding the timeframes of this disturbance, as well as what the original natural conditions and the magnitude of disturbance, is not always so clear, especially if disturbance began long before historical record keeping began. To determine if an environment has undergone disturbance, whether naturally induced or by anthropogenic means, proxies for different environmental variables can be used to create reconstructions of the palaeoenvironment. Proxies from ancient sediments are interpreted by applying what we know about the proxy in the present to the proxy assemblage from the past (Last & Smol, 2001; Smol, 2009). Commonly, cores extracted from lakes, bogs, swamps, floodplains and offshore continental shelves contain proxies such as pollen or charcoal that can be analysed to inform what the past environment was like and how it has changed in response to anthropogenic actions or otherwise. Combining the proxies with tephrochronology or radiocarbon dating provides an age control when reconstructing the environment, which enables pin pointing the time period of disturbance. This also enables calculating the pace of disturbance to an environment. Using pollen as an example, if the pollen assemblage from a core extracted from what is a swamp forest environment in the present, contains significant amounts of pollen types from hardy species which tolerate dry conditions, it implies that at some stage this environment was not swamp forest, and therefore has changed over time, possibly in response to a particular disturbance event. Whether this was a sudden or gradual change would require further analysis, such as applying an age control to the proxy, if one was available. This is why palaeoenvironmental reconstructions are particularly useful for deducing the pace at which disturbance took place, for example whether human modification to the landscape occurred rapidly within several decades or took thousands of years to impact upon the environment (McGlone, 1983; Wilmshurst *et al.*, 1999; Ruddiman, 2003).

There are many different types of proxies that can be used for environmental reconstructions. Table 2.1 lists some of the most common proxies and age controls utilised in previous research on disturbance. Examples of some of the proxies and age controls contained within the table are further elaborated, though the purpose of this study is not to define nor describe all available proxies and palaeoenvironment reconstruction techniques.

Table 2.1: Summary of main proxies and age controls used in previous palaeo reconstructions.

Name of proxy	How it is used
Pollen grains	Pollen and spores have an exine which is resistant to decay when preserved in an anaerobic environment, such as sediment layers in a lake or bog. Sampling these tells a story of what plants were in the local, regional or wider area.
Charcoal	Charcoal preserves well in soils and the amount and size (fine or coarse grained) can be used to infer when fires occurred. Fire frequency generally increases alongside growing human populations so is a good indication, particularly in wet environments, of human presence.
Radiocarbon Dating (Age Control)	Dating the carbon content of organic matter such as seeds or wood can give an approximate age of the surrounding material, assisting in building a timeline of an environment
Loss on Ignition	A measure of the amount of organic matter of lake and bog sediments, which can indicate rates of erosion and runoff in the surrounding catchment. This can also be used to infer the organic and inorganic carbon within the sediment.
Isotope ratios	The ratios of isotopes of particular chemical elements that have isotopes (e.g.

	oxygen, carbon) change over time in response to different processes. If the relationship with the driving processes is known, then isotope ratios can be used to infer how the environment has changed, such as changes in sea temperatures, air temperatures and diets of animals. Isotope ratios can be used from sediments, extracted air bubbles in ice cores, from shells and carbon material (e.g. bones).
Tree rings	Also known as dendrochronology, counting tree rings infer the age of the tree as each 'ring' represents a growth season. The thickness of the rings provides information about the environmental conditions (for example, thin rings, little growth, subpar growing conditions, could imply colder temperatures). It is also useful for calibrating radiocarbon ages as in some cases the exact age can be determined if the rings are distinct enough.
Sediment Stratigraphy (Ocean, lake, bog, floodplain)	Changes in sediment stratigraphy can be used to make inferences on the type of changes in the environment in the past. For example a sudden shift from dark clay soil to light sandy material indicates a change in sediment regime, where erosion and depositional processes may have been altered.
Trace Element Analysis	Using grab samples or analysing extracted cores for chemical elements can tell a story of the environment. Sudden peaks and falls in the abundance of particular chemical elements signals a change to the environment. For example an increase in Arsenic and Mercury is a sure sign of human intervention as these chemicals only occur minutely naturally in the environment but are common around mining areas.
Particle Size Analysis	Using a particle laser scanner measures the size of the grains in a sample. Using this information it can be easily deduced the type of sediment (clay, silt, sand) present, and how this changes over time indicates where disturbance may or may not have occurred.
Diatoms	Diatoms are single-celled organisms that have a very small siliceous exoskeleton, with huge morphological diversity between taxa. Diatom environmental preferences (salinity, temperature, etc.) along with measuring isotope ratios form the skeleton, can give information about previous water temperatures and climate fluctuations, and other environmental variables.
Fauna	Faunal remains firstly indicate presence/absence of a taxon in the local and/or regional area Secondly, they act as organic matter for radiocarbon dating to indicate when it was present. Particularly for New Zealand the use of rat bones has helped to determine the arrival of the first settlement of humans to the country.
Phytoliths	Phytoliths are microscopic structures made out of silica (and therefore preserve

	well in anaerobi environments) found in plant tissues. Similar to pollen, they infer what type of plants were in the area, though they can also be extracted from dental calculus, food preparation tools and ritual offerings, making them particularly useful for inferring previous diets of animals.
LiDAR/Aerial/photography imagery	Though not used for reconstructions before the photograph was created, using this proxy to demonstrate before and after a disturbance illustrates the nature of the disturbance (did it happen rapidly or slowly) and is very useful for modern reconstructions paired with other proxy information.
Tephrochronology (Age Control)	Every volcanic eruption has a unique geochemistry signature; no two eruptions are ever the same. Therefore when looking at the stratigraphy of soils tephra layers can be documented and compared across a wide area, radiocarbon dated for an age and then used to marry up multiple stratigraphic histories. In New Zealand, the Kaharoa Tephra is very useful as it has been dated to a relative degree of certainty and in conjunction with human evidence provides a time context of when humans settled.

In the Northern Hemisphere, pollen reconstructions are one of the predominant palaeoreconstruction methods used for determining natural and anthropogenic disturbance (e.g. Behre, 1988; Lopez *et al*. 2003; Marquer *et al*. 2014; Alba-Sanchez *et al*. 2015). For example, pollen records from Europe demonstrated that a mass shift from forest species to arable fields and pasture fields began at 6000-5500 cal. yr BP (Shennan, 2009) with grassland dominant by 3700 cal. yr. BP (Marquer *et al*. 2014) in response to settlement of humans. This also highlighted that though humans were in the area earlier than in other parts of the world, the rate of landscape change was significantly less than observed in places with a shorter human history, such as the Pacific Islands (e.g. Bayliss-Smith *et* al. 2003; Franklin *et* al. 2006). A similar trend was observed in North America though initially at a much slower rate due to the smaller population of Native Americans inhabiting the landscape prior to the explosion of European settlers. A sudden drop in native species such as *Casanea* and *Ulmus* were replaced by Poaceae spcies (McAndrews, 1988). This coincided with a rapid population growth from 30 million in the 15th century to well over 360 million by the end of the 20th century. The pollen record also shows the change in land use practices, as the mature forest species were replaced with open grasslands for cattle grazing.

Pollen-based vegetation reconstructions offer a simple indication of human disturbance in New Zealand, particularly in the last two hundred years due to early European settlers bringing exotic species from foreign lands (e.g. McGlone, 1983; McAndrews, 1988; Alba-Sanchez *et al*. 2015). Tree species such as macrocarpa and *Pinus radiata,* and pasture herbs such as *Plantago* and *Taraxacum,* have been used as clear indications of European settlers in New Zealand (McGlone & Wilmshurst, 1999; Horrocks *et al*. 2007; Sutton *et al*. 2008). Comparing sharp increases of Poaceae pollen alongside peaks of charcoal also indicates land clearance for pastures and rapid disturbance at a site (e.g. Behre, 1988; Wilmshurst *et al*. 2008).

Faunal remains have also been utilised to compare past environmental conditions to those at present in areas heavily modified by human activities (e.g. Dixit *et al*. 2000; Stewart *et al*. 2013). For example, Chironomid head capsules in lake sediment records can give information on oxygen levels in lakes pre- and post-human occupation (Dixit *et al*. 2003). This can highlight how practices such as poor waste management have caused an increased in eutrophication of lakes. Pin-pointing changes in oxygen levels via proxies like chironomids, in conjunction with some form of dating or age control (e.g. radiocarbon) also provides a timeline of when humans began modifying the lake environment to such a level it caused eutrophication (Smol, 2009). Diatoms have also been shown to be useful in reconstructing past lake levels which, in turn, reflect past precipitation levels (e.g. Tapia *et al*. 2003; Jones *et al*. 2012).

Variation in sedimentation rates in lakes, bogs and floodplains has also been shown to be a good indicator of human modification (Dunbar *et* al. 1997; Gomez *et* al. 1998; Glade, 2003; Richardson *et al*. 2014). Work by Xu (2003) on the Yellow River, China, has highlighted the impacts of changes in land use and increasing population growth putting pressure on the fluvial environment. Over the course of 130 years the sedimentation rate in the floodplain of the lower Yellow River had increased sharply from 2 to 8 cm yr^{-1}. This was strongly linked to population growth, which steadily increased from 8 million prior to 1850 to more than 50 million by 1995 (Xu, 2003). This study also highlighted that though humans had inhabited the floodplains of the Yellow River for thousands of years, only in the last couple of centuries has the rate of sedimentation, and therefore disturbance, increased rapidly.

Simonneau *et al* (2013) performed a multiproxy study on a 6 m core extracted from Lake Paladru (French Alps). The study produced a 10,000 year record of human disturbance including a reconstruction of sedimentation rates over time. The minimum accumulation rate was found to be 0.3 mm a^{-1} prior to human arrival based on dating of the extracted sediment core, but increased up to 1.8 mm a^{-1} by 1970. This year was regarded as nearing the peak of construction in the region, illustrating that the rapid expansion was having rapid effects in the surrounding environment they may not have been noticeable in the short term.

An emerging proxy for landscape disturbance is geochemistry of fine sediment sequences. This has been particularly useful in areas where mining for minerals occurred (Macklin *et al*; 1996; Hudson-Edwards *et al*. 1997). Historic mining practices resulted in mining waste and tills to be disposed of directly into nearby rivers, or situated near the river where they could easily become mobilised by rainfall events into the surrounding area. This led to metals such as Mercury, Lead and Arsenic being transported downstream to areas populated by communities, leading to health problems and degradation to the environment through polluted ecosystems (Rowan *et* al. 1995; Yim, 1976; Macklin, 1992; Macklin *et al*. 2006).

Measurements of metal concentrations in sediments from floodplains, lakes and bogs are made using techniques such as XRF scanning. These analyses allow researchers to pin point when mining (or other forms of disturbance) occurred in the wider region and therefore when human activities resulted in significant modification to the environment. There are many key chemicals which can be used as indicators, particularly Lead, Mercury, Cyanide, Zinc and Arsenic (Manju *et al*. 2014**;** Velasquez-Lopez *et al*. 2010; Ene *et al.* 2009) though any change in geochemistry may be an indication of anthropogenic impact. Hudson-Edwards *et al*. (1997) observed up to 6880 mg/kg of Lead and 1920 mg/kg of Zinc in mining areas on the Tees River in Northern England, with this concentration decreasing further downstream. The peak concentration values are more than 10 times the baseline levels described at the site by Lee (1989) indicating a significant modification to the area due to human disturbance. A significant difference in Cyanide and Mercury background levels compared to downstream sites was also observed at Nelson, Nevada. With less than 0.02

mg kg^{-1} of both metals observed above the site in comparison to up to 0.95 mg kg^{1} of Cyanide and 0.29 mg kg^{-1} of Mercury (Sim & Francis, 2008).

2.2. Disturbance in New Zealand

2.2.1 Overview

New Zealand has a brief human occupation history in comparison with the rest of the world. It was first colonized by the Polynesians (Maori), though the timing on their arrival is still hotly debated (Sutton *et al*. 2008; Wilmshurst *et al*. 2008). European settlement occurred in the last two centuries. These two periods of settlement led to rapid landscape transformation, firstly with forest clearance using fire by the Polynesians, and secondly with further fire and significant land use changes following the arrival of Europeans, who brought many new exotic species and large scale agriculture to New Zealand (McGlone, 1989, Ogden *et al.* 1998*;* McGlone *et al*. 1999, Anderson, 2003). To understand the spatial, temporal variation and magnitude of the disturbance, there have been numerous palaeoreconstructions performed in various parts of New Zealand, including across the North, South and offshore islands (e.g. Beveridge, 1973; Molloy *et* al. 1963; McGlone, 1983) to determine how New Zealand has changed over time from both natural and anthropogenic disturbance events (e.g. Wilmshurst *et al.* 1999; Sutton *et al*. 2008; McWethy *et al.* 2010).

Of particular interest was work by McWethy *et al*. (2010) who produced a comprehensive summary of anthropogenic disturbance in the South Island. Their research not only highlighted the role of natural factors (e.g. difference in elevation, subsequent rainfall patterns) impacting the vegetation patterns in the South Island but also summarized that the main vegetation changes that occurred in the South Island were due to anthropogenic impacts. These impacts began to occur within two centuries of Maori arrival, within what they defined as the 'Initial Burning Period'. As of yet there has not been a similar compilation of disturbance records from the North Island (and outlying islands in close proximity to the mainland) to deduce if it also showed similarity in rapid response to human impacts.. To date the focus of research has been on when humans, specifically the

Polynesians, arrived in New Zealand and began disturbing the natural landscape, rather than on the magnitude and pace of disturbance.

Some of the challenges to performing such a review include the need to separate the anthropogenic disturbance events found in the reconstructed palaeo environments from natural ones. This can be a difficult task when the pre-human environment may have undergone multiple natural disturbances, such as fires, earthquakes or volcanic activity, conditions which are present in New Zealand. McWethy *et al*. (2010)'s review of the South Island disturbance sites separated the natural from the anthropogenic, yet this has not been done for the North Island. Therefore the first part of this thesis reviews the disturbance in the North Island of New Zealand in an attempt to concisely summarise what has occurred in this region since human arrival as well as the spatial, variation and speed of the disturbance.

2.2.2 New Zealand Setting

New Zealand is an archipelago with over 700 offshore islands, situated in the Pacific Ocean in the Southern Hemisphere. It is part of the mainly submerged continent Zealandia. Changes in eustatic sea level, along with tectonic movements over tens of millions of years have resulted in the present land mass known as New Zealand today (Fleming, 1979). It straddles the boundary between the Indo-Australian and Pacific plates, giving rise to a dynamic environment characterised by earthquakes, volcanic eruptions and tsunamis (Adams *et al*. 1994). The archipelago is over 1,600 km long, and consists of the mountainous Southern Alps that essentially split the South Island down the middle, with lower and somewhat less dominant mountain ranges occupying the lower and central parts of the North Island. Due to its position in the south of the Pacific (34°-47°S) westerly winds dominate the region, causing a distinct west – east pattern across the country (Alloway *et al*. 2007). The climate at present can broadly be summarised as subtropical in the north to subalpine in the south with a generally temperate climate across the central part of the country. The mountainous terrain causes significant variations in rainfall across the country, with the highest amounts along the west coast of the South Island and the lowest in the east (Adams *et al*. 1994).

2.2.3 Disturbance prior to Human Occupation

Landscape disturbance occurred prior to human arrival in New Zealand, in response to both short-term events such as storms, natural fires, volcanic eruptions, and longer-term processes such as climate change and tectonic processes (Wilmshurst *et al* 2008; Sutton *et al*. 2008). These disturbances have been recorded in numerous studies covering a variety of timeframes, including within the last 1,000 years, to the Last Glacial Maximum and beyond. Disturbances recorded in these studies have been attributed to shifts in climate and short term events (McGlone, 1985; Alloway *et al*. 2007; McGlone & Basher, 2012; Newnham *et al*. 2013, Li *et al.* 2014).

Areas such as Central Otago experienced numerous fire events 4000 - 3000 years ago, as recorded in lake samples, which significantly predates any other evidence of human arrival. These fires are associated with drops in Podocarp pollen directly after the event, with a general increase in grass species and short, hardy shrubs (Vandergoes *et al*. 1997). Further north, at Onepoto maar near Auckland, declines in pollen of tall hardwood species and a rise in shrub pollen immediately after tephra layers records disturbance caused by volcanic eruptions (Augustinus *et al*. 2011). Earthquake-triggered disturbances are also particularly significant in the New Zealand setting, as some studies have shown they can contribute to the formation of lakes (Newnham *et al*. 1998). For example, Lake Waikarimoana was formed approximately 2200 cal. yr BP, when a large landslide (interpreted as the response to a major earthquake), blocked an existing river, and drowning the valley, causing what may have been a short term disturbance to the area (earthquake triggered landslide) into a long term disturbance event that forever changed the system (Newnham *et al*. 1998). Events such as this shaped the landscape and modified it well before the intervention of humans. This further highlights the importance of reconstructing past environments for untangling man made events from natural.

The location of New Zealand within the southern ocean and in the westerly wind belt has made it particularly sensitive to climatic shifts (Alloway *et al*. 2007). These have resulted in long term changes to the landscape, which have been captured in palaeo reconstructions. What follows is a brief summary of the natural changes which occurred in New Zealand since the Last Glacial Maximum, identifying changes that occurred naturally. This is particularly important to note as some natural events can have similar signatures as those caused by humans, making the timing of the events extremely important to determine to separate the events.

In the South Island, cores taken from Stewart Island, Te Anau bog in Southland, Takitimu Mountains in western Southland and Kawarau Gorge in Central Otago have shown that these regions experienced several shifts in vegetation patterns over several thousand years (McGlone *et al*. 1995; McGlone & Wilson, 1996; Vandergoes *et al*. 1997; Wilmshurst *et al*. 1999). From ~7,000 cal. yr BP the vegetation consisted of *Podocarpus spp*. and fern species, primarily *Pterdium,* that were adapted to less seasonality, with warm winters and wet summers and abundant moisture (McGlone *et al.* 1995 & McGlone & Wilson, 1996). Approximately 4,800 cal. yr BP marks the height of the forest vegetation in this region, with a mixed podocarp hardwood and beech forest dominating the landscape (Vandergoes *et al*. 1997). From 3,000 cal. years BP dry conditions increased, shown in these records by an increase in shrubs and *Poaceae*, which are adapted to moisture deficiencies and increased wind flow.

Similar to the South Island, a distinct west-east coast vegetation pattern existed due to the westerly wind flows across the island (McGlone *et al.* 1993; Newnham *et al*. 1999; Wilmshurst *et al*. 1999) though with a less pronounced 'wet' west coast. On the east coast of the North Island, a vegetation shift occurred at approximately 4,000-3,000 years, similar to those sites already mentioned (Gomez *et al*. 2004). The western North Island experienced a decline in frost-sensitive species, as well as an increase in Fuscospora *spp.* (McGlone *et al.* 1993; Gomez *et al.* 2004). Also evidence from off-shore marine sediments attributed this vegetation change and others across New Zealand, to an increase in Circumpolar Westerly Vortex, Walker Circulation, and ENSO systems (Gomez *et al*. 2004).

In the far north, studies have shown that between 12,000-6,000 cal yr BP there have been increases in *Dacrydium cupressinum* along with other angiosperms and podocarps in this region. Shrub species increased in the region between 6,000-2,000 years ago which has been attributed to drier conditions in the region (Newnham *et al.* 2007; Elliot *et al.* 1998). The forest after 2,000 years is still composed of forest species but with a reduced amount of angiosperms with open grassland areas in the far north, and with large amounts of forest disturbance indicated by coarse and dense sediment layers, particularly at the Lake Tauanui Catchment, Northland (Elliot *et al*. 1998).

2.2.4 Colonisation of New Zealand

Numerous studies conducted around the globe have demonstrated the impact human settlement can have on a previously pristine environment (e.g. Ralska-Jasiewiczowa & van Geel, 1992; Craft & Casey, 2000; Know, 2001; Janet *et al*. 2006; Escobar *et al*. 2013). These impacts result from processes/activities such as clearing of the land after first arrival, to changes in landuse practices over time altering slope stability. Such activities alter soil geochemistry (changes in the amount of trace elements present), water and air quality, and can result in removal of indigenous flora and fauna (McWethy *et al*. 2010; Glade, 2003; Sutton *et al*. 2008).

New Zealand was one of the last places on earth to be inhabited by people. With such a short prehistory, one would expect to see less of an impact on the environment compared with continents such as Europe and North America. However this is not the case. Palaeovegetation reconstructions have shown that 85-90% of New Zealand was covered in some form of forest prior to human arrival (McGlone, 1989). By the time European settlers arrived, just over 65% of New Zealand was covered by forests (McWethy, 2009; McGlone & Wilmshurst, 1999; McGlone, 1983; See Figure 2.1). At present, forest cover on the South Island and North Island has been reduced by 40% and 90% respectively (Ogden *et* al. 1998).

However it remains to be seen conclusively when the first Polynesian settlers arrived in New Zealand, with three main theories of New Zealand's prehistory proposed: the 'long' (>1500 years), 'short' (<600 years) or 'intermediate (~1000 years) (Sutton *et* al. 1987; McGlone & Wilmshurst, 1999; Anderson, 2003; Sutton *et al*. 2008).

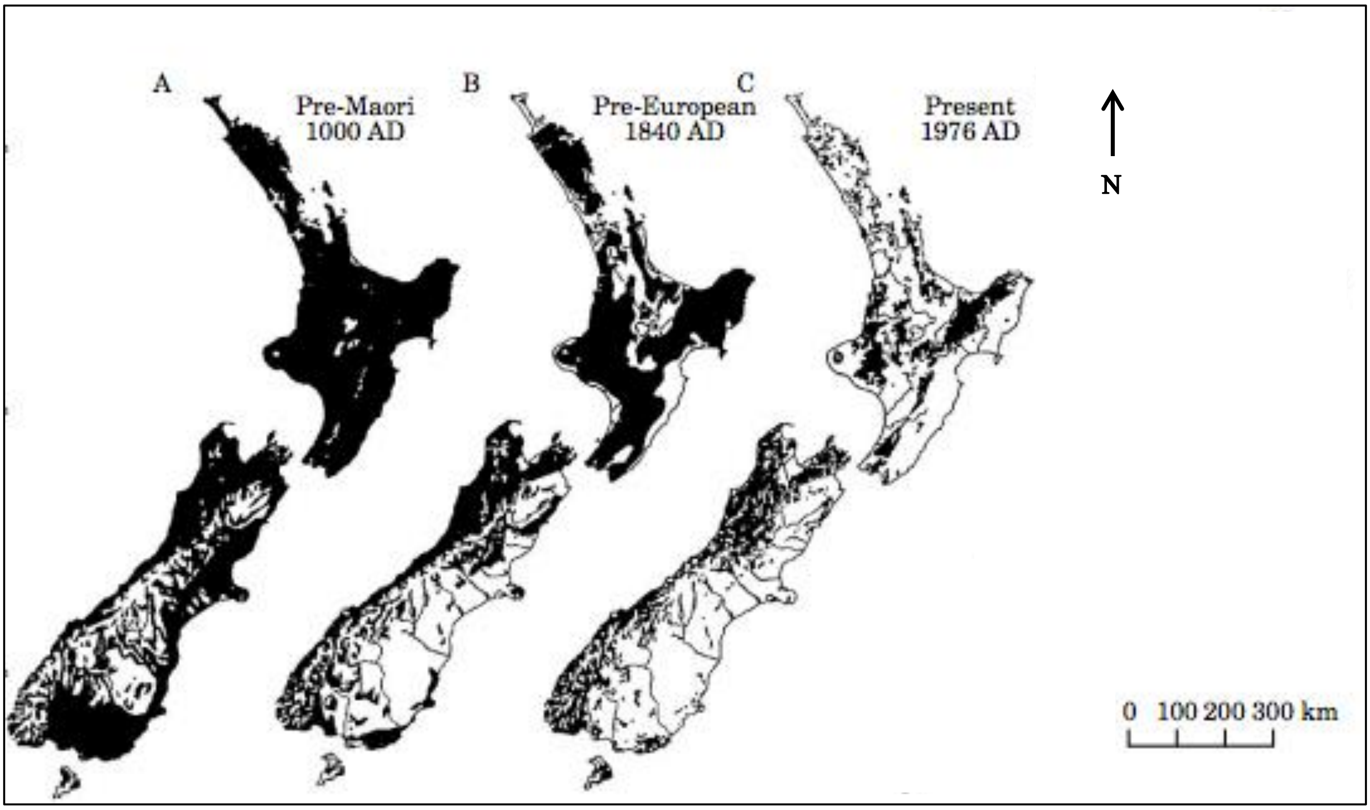


Figure 2.1: Changes in New Zealand vegetation cover. A: Pre-Maori, B: Pre-European and C: Vegetation cover in 1976. Adapted from Tomlinson (1976)

The 'long' history proposed that humans colonized East Polynesia from West Polynesia as early as 200 B.C. (Kirch, 2000; Kirch, 1996; Anderson, 2003; Kirch & Green, 2001) whereas the 'short' chronology began at ~ 815 cal yr. BP. (Anderson, 2003; Kennett *et al*. 2006**;** Spriggs & Anderson, 1993). There is significant research supporting both sides (e.g. Sutton *et al*. 2008; Wilmshurst *et al*. 2008). Some of the first evidence of human arrival was from dating archaeological sites e.g. Davidson, 1984). Since the late 20th century to the present, there is a growing amount of evidence from charcoal and pollen records, combined with tephrochronology from cores extracted from lakes and bogs (McGlone, 1989; Wilmshurst *et al.* 1999; Hog *et al*. 2002**;** Horrocks *et al*. 2000). Several sites have also discovered *Rattus exulans* bones (Holdaway, 1996; Anderson, 2003; Wilmshurst *et al*. 2008) which have been radiocarbon dated to determine the first arrival of Polynesians to New Zealand. One of the main sources of contention was based on Pacific Rat (*Rattus exulans*) bones that were found in an excavated site (Holdaway, 1996; Holdaway, 1999). Some studies have used this as evidence of the 'long' history of human occupation (Sutton *et al*, 2008; Worthy, 1999) yet subsequent dating of Pacific Rat bones has not been able to duplicate these results and instead support the settlement of humans ~735 cal. yr CP. (Wilmshurst *et al*. 2008). Though there is still disagreement on the timing of the first wave of settlement, it is accepted that there was human occupation by ~800 cal. yr BP based on the above combined evidence (Sutton *et al.* 2008; Li *et al*. 2014; Richardson *et al*. 2013).

2.2.5 Evidence of Anthropogenic Activities

New Zealand had two waves of settlement; firstly the Polynesians and in the last two centuries the Europeans. Both left similar but also distinct disturbance markers in the prehistoric environment history of the landscape.

The impact of Polynesian settlement since ~800 cal. yr BP is in the form of increased charcoal, vegetation changes (McWethy *et al*. 2010; McGlone, 1983) and decreased indigenous fauna. After the arrival of humans there was a steep decline in indigenous species, including the *Dinornithiformes* (Moas), *Harpagornis moorei* (Haast Eagle) and 38 other bird species along with a bat and 3 amphibious species (Worthy, 1999). The appearance of microscopic charcoal fragments within subsamples of sediment extracted from cores is a key indicator of the first settler in an environment, particularly at sites in wet, high altitude environments (McWethy *et al*. 2010). Polynesians regularly burned the native forest to clear the land to encourage bracken fern regeneration, as well as to potentially assist in Moa hunting (Anderson, 1979; Sutton, 2008). Within the pollen record, a spike in *Pteridium* spores and a decrease in pollen of hardwood species is a clear sign of human occupation (Mildenhall, 1979). The pollen and charcoal evidence from a site can be combined with archaeological and oral Polynesian history, which further supports disturbance induced by anthropogenic activities (Gates, 2013).

Deforestation of the New Zealand landmass continued as the settled Polynesian population expanded but significantly increased after European settlement, approximately 200 years ago (Wilmshurst *et al*. 1999; Sutton *et al*. 2008; Li *et al*. 2014; Richardson *et al*. 2014). European colonisation had significant impacts not only on the vegetation but also to rates of erosion and sedimentation, with flow on to the geomorphological features of the landscape and a decline in native species (Pawson & Brooking, 2002). Not only did vegetation patterns further change under European land use practises with the introduction of new exotic species, but activities such as large scale logging and mining changed the geochemistry of the soil. This was altered by using chemicals in the processes that were very low or not naturally found in the surrounding environment. These meant levels of trace elements, such as Zinc, Iron, Potassium, Nitrogen and Arsenic were altered, reaching levels that would not be possible naturally. For example, the practice of crushing and Mercury amalgamation in mining in the Coromandel caused increased levels of Arsenic and Mercury in surrounding soils and water ways as it was released from rocks significantly faster than they would naturally be eroded by natural chemical weathering (Craw & Chappell, 2000). The change in landuse with the conversion of forest to open grassland for grazing and dairying resulted in increased amounts of Nitrogen and Potassium, as these chemicals were added to the soils to increase their productivity (Zabowski *et al*. 2002), which led to pollution of waterways (Craw & Chappell, 2000) and increased sedimentation through unstable slopes eroding faster without the forest cover (Reid & Page, 2002).

Chapter 3: North Island Case Study Review

3.1 Aim

Most studies which have captured evidence of disturbance in the pre-European environment have focused on investigating the timing of human arrival, because of the strong ties between humans and disturbance (e.g. Ogden *et al*. 2003; Wilmshurst *et al* 2008; Sutton *et al*. 2008). Furthermore, some studies have attempted to quantify the amount of change that occurred following the human induced disturbance (e.g. Reid & Page, 2002; Glade, 2003; Ellis *et al*. 2004). What has not been done is an assessment of this body of work as a whole to compare and contrast the evidence of disturbance across an entire country. This would enable the analyses of links and trends of disturbance that could provide information on areas that were susceptible to disturbance and what then could be done for future management of the disturbed area. McWethy *et al*. (2010) has done this for the South Island of New Zealand, but the North Island has not been attempted. This review collates a wide range of literature, some unpublished, on studies that have reconstructed past environments to determine if disturbance has occurred, and to analyse the patterns, similarities and differences across the North Island.

3.2 Method & Limitations

To find the information regarding disturbances in the North Island in the late Holocene, a literature review was undertaken. This involved searching through various search engines, libraries, and inquiring with other researchers to find the literature to pull out the key facts required for this review. Criteria for studies to be included in this review required that they were recreating past environmental histories, not specifically if the purpose of the research was to find anthropogenic disturbance. This yielded a greater variety of research using a multitude of proxies and did not eliminate potential studies that did not find evidence of human disturbance. The information was collated into a table with the key information described. Once collated, the information was summarised into graphs, firstly showing the studies selected, where they are located and the name of the site. The research was then categorized broadly on the type of proxies used, to illustrate the main methods used to identify changes in the landscape. This was then broken down into which studies did show evidence of anthropogenic disturbance. Finally, the sites were then graphed comparing the underlying geology and rainfall to compare and contrast the areas that were disturbed and to determine if any patterns could be identified.

There are several key limitations that need to be noted of this review. Firstly, because of the diversity of studies used there is a great variation in the temporal resolution of the individual records. When subsamples for proxies such as pollen, phytoliths and Particle Size Analysis (PSA) are closer together they can reveal environmental changes at a higher resolution than is possible with widely spaced samples (Joosten & de Klerk, 2007). Therefore studies with low-resolution sampling have a greater risk of missing disturbance events, in extreme cases giving the impression that no anthropogenic disturbance occurred at the site.

Secondly, and not unrelated to the first issue, is the diversity of the research aims of the individual studies. If the primary purpose of the research conducted was not to determine disturbance at the site then the most recent history may not have even been analysed. This is often the case for studies on palaeo reconstructions of past climatic events, which are more focused on recreating a long history than the most recent changes in the landscape (e.g. Augustinus *et al*. 2011).

Thirdly, while all efforts have been made to collect as much information on late Holocene disturbance as possible, the review is by no means all of the evidence of disturbance in New Zealand. Not all studies, particularly in the case of unpublished material contained in theses, were able to be found and used as part of this review. This should be treated as a strong foundation that can be added to in future, further providing evidence of the spatial and variation of disturbance across the North Island of New Zealand and should not be treated as a complete final product but ever growing.

3.3 Results & Discussion

Table 3.1 summarises the main findings from each of the studies that was reviewed, including the assigned number given to the site as displayed in Figures 3.1-3.5. Table 3.2 defines how the categories were assigned based on the proxies used.

Number allocated to site	Site Location	Disturbance proxy and/or age control	Evidence of human disturbance?	Length of core (m)	Age of core	Depth of disturbance (m)	Sedimentation rate before	Sedimentation rate after	Polynesian or European first?	Resolution	Author
1	Lake Taumatawhana	Pollen, Charcoal	Yes	4	800 cal. years BP at depth of disturbance, core in total 5000 years	1.12			Polynesian	10 cm	Elliot et al. 1995
2	Kaeo Catchment	LiDAR, sedimentology, radiocarbon chronology, XRF analysis, GPR	Yes		N/A		0.3-0.7mm per year	8mm/ per year, 13.5 mm per year after European	Polynesian & European	10 cm	Richardson et al. 2014
3	Rangihoua Bay	pollen, Charcoal, loss on ignition, trace elements, diatoms	Yes	4.3	at 0.9m 492+/-49 cal. years BP . Age at bottom of core = 7400 cal. years BP	1.08			Polynesian	<10cm >1cm	Horrocks et al 2007
4	Wharau Road Swamp	pollen, Charcoal, grain-size PSA, trace elements	Yes	3.55	Total core = 4300 cal. years BP, major disturbance at 600 cal. years BP	1.2	0.56mm/year	2.00mm/per year	Polynesian	10 cm	Elliot et al. 1997
5	Panguru Catchment	LiDAR, sedimentology, radiocarbon chronology, XRF analysis, GPR	Yes		N/A					10 cm	Richardson et al. 2014
6	Lake Tauanui	Pollen, Charcoal , radiocarbon	Yes	4	Total core = 5400 cal. years BP, disturbance = 1000 cal. years BP	1.25 Maori, 0.65 European				10 cm	Elliot et al. 1998
7	Waimamaku Catchment	LiDAR, sedimentology, radiocarbon chronology, XRF analysis, GPR	Yes		N/A			3.3-3.7mm per year		10 cm	Richardson et al. 2014
8	Mangakahia Catchment	LiDAR, sedimentology, radiocarbon chronology, XRF analysis, GPR	Yes		N/A			5.6-10.1mm per year		10 cm	Richardson et al. 2014
9	Tarahoka & Omaia Clearings, Waipoua Valley	Pollen, Charcoal, radiocarbon, tree cores and cross-sections of coores (ring sequences), vegetation plots for current vegetation	Yes	0.9	Disturbance by Polynesians at 44-46 cm = 487+/- 60 cal. years BP	0.44-0.46 Maori, 0.49 Euro post-clearing burning (~1800) 0.27 Euro (~1900)			Polynesian & European	5 cm (for core) (0.01m for kauri tree rings)	Ogden et al 2003
10	Maungatapere & Rawhitiroa basaltic cones	Pollen, Charcoal, Radiocarbon dating	Yes	5 m Maungatapere, 4.8 m Rawhitiroa	10530 +/- 136 cal. yr BP for Maungatapere, 2775 +/- 52 cal. yr BP for Rawhitiroa	Kaharoa Tephra at 0.4 in Rawhitiroa, changes at 680 cal year BP in Maungatapere at 0.32 m, 750 cal year BP for Rawhitiroa at 0.57m based on pollen	4.7 cm/per year = Maungatapere, 13.5cm per year = Rawhitiroa	Rawhitora above tephra layer 5.7 cm/per 100 years	Polynesian	10 cm	Gates, 2013 (unpublished)
11	McEwan's Bog	Pollen ,Charcoal, Radiocarbon dating, loss on ignition	Yes	1.8 m	6,500 cal. years BP	0.16-0.12			Polynesian & European	5 cm intervals	Kershaw & Strickland, 1988
13	Te Rerenga, Coromandel	dating Pacific rat bones, sediment layers, radiocarbon dating	Yes	Peat profile, 1.20 m	N/A	Kahoroa tephra, 75-100 cm dated at 1314 +/- 12 AD; oldest seeds 1270-1420 AD			Polynesian	5 cm for seeds	Wilmshurst & Higham, 2004
14	Lake Pupuke	geochemistry, stable isotopes, mineral magnetism, tephra-based radiocarbon dating, x-ray radiography to detect sedimentary structures, dry bulk density and water content	Yes	5.9 m	~9, 490 cal. years B.P. Rangitoto Tephra formation at 27.6-28.3 cm = 550 cal years BP. Taupo Tephra = 168.5-168.8 cm = 1718 cal years BP	Rangitoto volcanic eruption at 550 cal yr BP., at 610 cal. yr BP above this human evidence therefore human impact just prior to eruption (34-35 cm)	0.11 cm per year from Taupo to Rangitoto tephra layer (Horrocks et al. for same lake got sedimentation rate of 13 cm per year)		Polynesian	subsampled for thin sections a t0.7-1.9 cm; 1 cm in field logging (i.e. very high resolution) for bulk samples were 1-2 cm subsamples	Striewski et al. 2009; Horrocks et al. 2005
16	Kauaeranga Valley	pollen, radiocarbon dates, Kaharoa Tephra, charcoal	Yes	7 cores from 1.2-3.1m in depth	1800 cal years BP	At ~750 BP - 480 BP depending on which core; approximately 80 cm- Kaharoa dated at 665 at 76 cm; Maori straight after this, European at 40 cm	average before Kaharoa tephra = 1.7 mm per year		Both; Polynesian at 1201-1470 AD. European at 40cm depth	5 -10 cm	Byrami et al. 2002
17	Waikato Forest	Nutrient availability, mineralogy, trace elements	NO		N/A						Zabowski et al. 1996
18	Mayor Island	Pollen, charcoal, radiocarbon dating	Yes	3.95 m	3000 cal years BP	AT 450 BP - about 95 cm in core			Polynesian	10 cm or closer at important levels	Empson et al 2002

19	Lake Rotokauri	Pollen, sediment, radiocarbon date, charcoal	Yes	4 m	13000 cal year sBP	0.8-0.55m, 0.1 m for exotics; At 1.05 m = 3,000 BP, peak in ferns at 0.55 cm (Polynesian?_	0.23 mm/per year	0.56 mm/per year	Polynesian = 0.55 m (dated at 775-670 cal yr BP) & European = 0.10 m	10 cm, representing about every 100 years or so	Newnham et al. 1989
20	Lake Okoroire	Pollen, sediment, radiocarbon date, charcoal	NO	~2.6 m	16000 cal years BP	0, at ~0.95 m = 4,000 BP				10 cm, representing about every 100 years or so	Newnham et al. 1989
21	Lake Rotomanuka	Pollen, sediment, radiocarbon date, charcoal	Yes	3.5	18000 cal years BP	0.8m, 0.1 m for exotics; At 0.5m 2,000 year BP			Polynesian = 0.25m (?)& European = 0.1m	10 cm, representing about every 100 years or so	Newnham et al. 1989
22	Kohika Swamp	Pollen, charcoal, radiocarbon dating, kaharoa tephra	Yes	1.8	1365 BP	*Disturbance at 660 BP = 1.10 m			Polynesian	~10 cm	McGlone 1983
23	Rangitaiki	Pollen, charcoal, radiocarbon dating, tephras	Yes	1.7	2100 cal years BP	*Disturbance at 660 BP = 0.2 cm			Polynesian (and maybe European? Not separated)	5 cm	McGlone 1983, Campbell et al. 1973
24	Waitomo Catchment	Karst dating, creating a Karst Index	No		N/A						van Beynen & Bialkowsha-Jelinska 2012
25	Holden's Bay, Rotorua	Pollen, charcoal, radiocarbon dating, kaharoa tephra	Yes	0.93m	4,000 cal years BP	*Distubance at 660-670 BP; 0.34 m; European disturbance (?) = 350 BP 0.22m			Polynesian (and maybe European?)	5-10 cm	McGlone 1983, McGlone 1983
27	Repongarere Swamp	Pollen, Charcoal, tephra chronology, Loss on ignition, radiocarbon dating	Yes	5 m	5500 years BP	0.53 m at 665 yr BP			Polynesian (couldn't separate from European)	2 cm above tephra layers, 5cm	Wilmshurst et al 1999
28	Lake Waikaremoana	Pollen, Charcoal, tephra chronology, radiocarbon dating	Yes	0.995 m	1850 cal. years BP	0.08 m for European at 100 cal BP years, 0.35 m for Polynesian at 375 years BP			Polynesian & European	5 cm	Newnham et al 1998
29	Tiniroto Lake	Pollen, Charcoal	NO	5.42 m	5,300 cal. years BP	2,300 cal. yrs BP at 2.25 m				10 cm, 2-3 cm above tephra	Li et al. 2014
30	Lake Taupo, Waipehi Bog	Pollen - Mainly Pterdium & Gramineae	Yes		N/A	*Disturbance at 770 BP - 0.52 m			Polynesian	4 cm	McGlone 1983, Sutton et al. 1987
31	Mimi, Taranaki	dating Pacific rat bones, sediment layers, radiocarbon dating	Yes	0.5	N/A	1140-1240 AD oldest gnawed seeds			Polynesian	5 cm	Wilmshurst & Higham, 2004
32	Lake Rotonuiaha	Pollen, Charcoal, tephra chronology	Yes	6 m	N/A	*Disturbance at 500 years cal BP	1.7 mm/yr	2.6 mm/yr = polynesian, 10.5 mm/yr = european		15 cm	Wilmshurst 1997
33	Waitoetoe, Taranaki	dating Pacific rat bones, sediment layers, pollen, radiocarbon dating	Sort of - pollen showed above peat layer changes, but no evidence from seeds of rat presence	0.85	Below peat (below 0.1 returned 1822 +/- 52 BP at 40 cm) 0.10 marks arrival of humans (?). Total age of core (base of peat) 2310 +/- 59 BP.	0.1 m - shown through pollen analysis as layer above peat.; no seeds			Polynesian	5 cm	Wilmshurst & Higham, 2004; Wilmshurst et al 2004
34	Gibson's Swamp	Pollen, Charcoal, radiocarbon dates	Yes	0.94 cm	13,000 BP	At 1850 AD; 0.105 m	0.01 mm/yr post-taupo eruption	0.08 mm/yr	European	0.5 - 2 cm	Horrocks & Ogden 1998
35	Lake Tutira	Pollen, Charcoal, tephra chronology	Yes	6 m	N/A	*Disturbance at 500 years cal BP	1.7 mm/yr	2.7 mm/yr = Polynesian, 13.8 mm/yr = European		15 cm	Wilmshurst 1997; Eden & Page 1998
36	Mt Taranaki (Potaema Swamp)	Pollen, charcoal, radiocarbon dating, kaharoa tephra	Yes	1.3 m	No age for bottom of core.	*Disturbance at 450 BP at ~1.10 m			Polynesian	~10 cm	McGlone *et al.* 1988
37	Lake Waiau Swamp	Pollen, Charcoal, radiocarbon dating	Yes	5 m	3 m = 2920 +/- 160 BP	1 m at 685 cal BP			Polynesian	20 cm	Bussell, 1988

38	Lake Poukawa	Pollen, Charcoal, radiocarbon dating	Yes	1.6 m	~1000 BP at 0.9 m	0.9 m for polynesian, 0.3 m for European			Polynesian and European	10 cm	McGlone 1983, McGlone 1978
39	Lake Horowhenua	Pollen, Charcoal, radiocarbon dating	Yes	~ 5.5 m	5500 – 6500 cal. years BP	0.5 m			European/indistin guishable	40-50cm	Fox 2011 (unpublished)
40	Lake Waitawa	Pollen, Charcoal, radiocarbon dating	Yes	3 m	3000 – 6500 cal. years BP	0.85 m, 0.35 m			Polynesian and European	10 cm	Fox, 2011 (unpublished)
41	Pauahatanui Inlet	Pollen, radiocarbon dating	Yes	13 m	8300 cal. years BP	0.4 m 600 cal yr BP, and ~0.25 m 120 cal yr BP			Polynesian and European	10 - 20 cm	Mildenhall 1979, McGlone 1983
42	Wellington Harbour	14C and 137C chronologies, grain size analysis, pollen, trace elements	Yes				2.1 mm/yr	38.2 mm/yr	European		Goff 1997, Glade 2003
43	Continental Shelf - Poverty Bay	Pollen, Charcoal, tephra chronology	Yes	2.5 m, water depth 63 m	~4800 yr BP	0.55 m European, 0.75 Polynesian			Polynesian & European	5 cm	Wilmshurst et al. 1999
12*	Great Barrier Island, Awana Swamp	Pollen, charcoal, sediment analysis	Yes	5.6m	7000 yr BP	Kaharoa tephra, 600 cal. yr BP in pollen ,no disturbance in sediment. 0.40 5 cm sample tephra layer			Polynesian	10 - 20 cm intervals	Horrocks et al. 1999
12*	Great Barrier Island, Southern Kaitoke Forsythes Paddock	Pollen, sediment, radiocarbon date, charcoal	Yes	7.0 m	7,500 yr BP	Kahoroa tephra, 600 cal yr BP, other fires 1750 cal year BP and 12900-970 cal yr BP, 18 cm				10- 50 cm samples	Horrocks et al. 2000
15*	Waihi Beach mire	pollen, radiocarbon dates, tephra dates, charcoal	Yes		4600 cal years BP	at 700 yr BP	0.11 mm/per year	0.21 mm/per year	cannot distinguish between them	5 cm at lower end for pollen; up to 25 cm	Newnham et al. 1995
15*	Papamoa mire	pollen, radiocarbon dates, tephra dates, charcoal	Yes		2900 cal years BP	at 700 BP depth = ~17cm	1.15 mm/per year		cannot distinguish between them	5 cm at lower end for pollen; up to 25 cm	Newnham et al. 1995
44	Lake Papaitonga	Pollen, Charcoal, radiocarbon dating	Yes	5.4 m	5400 – 6500 cal. years BP	~1.0 m			European/indistin guishable	~25 cm	Fox 2011 (unpublished)
45	Waverley Beach	Pollen, Charcoal, radiocarbon dating	NO	8.5 m	7000 BP					20 cm	Bussell, 1988
46	Whangape Harbour	Pollen, sediment, radiocarbon date, charcoal	Yes	6.3 m	8000 cal years BP	1.25 mm ~ 700 yr BP	1.7 mm/yr	4.6 mm/yr	Polynesian	low; 50-100 cm	Horrocks et al. 2001
12*	Harataonga Bay, Great Barrier	Microfossils, pollen, phytoliths, coprolites, radiocarbon	Yes		N/A	at least 467 +/- 60 cal years BP, above Kaharoa at 665 cal year BP			Polynesian	4 samples	Horrocks et al. 2001
26	Waipaoa Valley	Sediment budget, aerial photography	Yes		N/A				European		Reid & Page, 2002
47	Lake Namunamu	pollen, radiocarbon , charcoal	Yes	2 m	2000 cal years BP	0.27 m european, 0.67-0.77 m polynesian			Polynesian & European	10 cm	Wilson, 1999 - unpublished
48	Lake Maungarataiti	pollen, core stratigraphy, charcoal, radiocarbon	Yes	3.3m	3200 BP	0.5 m			Polynesian	20-25 cm	Foote, 1996 unpublished
49	Lake Pauri	pollen, core stratigraphy, charcoal, radiocarbon	Yes	2.3 m	3000-3500 cal. years BP	1.49 m = polynesian, 0.7 m= european dated at 1840 AD			Polynesian & European	23 cm	Morley, 1994 - unpublished
50	Deep Hole, Waikato	pollen, charcoal, radiocarbon	Yes	4.6 m	6500 BP	1.25 m = european at 1250 years B.P.. At 0.4 m = 1950 AD			European	20 cm	Lees et al. 1998
51	Deep ocean core eastern North Island	Pollen, sedimentology, charcoal	Yes	35 m	1032 +/- 58 cal. years BP at 0.19 m (637 cal years. BP)	0.44-0.45 m @ 1400 cal year BP (550 AD)	0.35 kyr-1	0.35 kyr-1	European	1 cm - 4 cm	Elliot et al. 2003
52	Otaki Plain, Horowhenua	Pollen, tephra/ash layers	Semi	3.6 m	~ 6000 cal. years BP	0.7 m, 1.40 m			0.7m early Maori, 1.4 m maybe european but could be natural	25 cm	Dickson, 1997
53	Lake Alice, Rangitikei	Pollen, charcoal, radiocarbon dating	Yes	3.45 m	2000 cal. years BP	1.46 m & 0.75 m	0.40 cm/yr - 0.14 cm/yr	0.1 cm/yr - 0.24 cm/yr	Polynesian & European	25 cm	Purdie, 2004 (unpublished)

54	Lake Colenso	pollen, tephra layers, radiocarbon dating, geochemistry trace elements, sedimentology, ostracods & molluscs	NO	3.26 m	1800 cal. years BP					5 cm	MacDonald-Creevey 2011 (Doctoral Thesis)
55	Taupo, Central North Island	Relationships between mean annual temperature, rainfall, solar radiation modelled to determine past conditions and most likely vegetation patterns during the changes in climatic conditions	NO	N/A	N/A						Leathwick & Mitchell, 1992
56	W4 East Coast Floodplain	Sedimentology, seismic analysis of events, tephra chronology	NO	N/A	N/A					3 cm	Gomez et al. 2004
57	MD972122 Shelf	Sedimentology, seismic analysis of events, tephra chronology	NO	N/A	N/A					3 cm	Gomez et al. 2004
58	MD972121	Sedimentology, seismic analysis of events, tephra chronology	NO	N/A	N/A					2 - 10 cm	Gomez et al. 2004
59	P69 Marine Core south eastern North Island	Pollen, Charcoal, tephra chronology, radiocarbon dating	YES	6.63 m	26,000 yr BP	0.3 m at 800 yr BP			Polynesian	5 - 40 cm	McGlone 2001
60	Lake Maratoto	Pollen, Charcoal, tephra chronology, radiocarbon dating	NO	3 m	16,000 yr BP						Lowe et al. 1980
61	S803 Marine Core Bay of Plenty	Pollen, Charcoal, tephra chronology, radiocarbon dating	NO	~ 3 m	55,000 yr BP						McGlone 2001
62	Kaiparoro Clearing, Tararua Range	Pollen, Charcoal, carbon & nitrogen soil profiles, tephrostratigraphy, modern pollen rain, aerial photography	NO	1.40 m	3,500 yr BP					20 cm	Rogers & McGlone, 1994
63*	West Ballantrae	Pollen (monolithic samples taken), stratigraphy described	NO	2.9 m	12,900 - 13,000 yr BP					5 cm	Lees, 1986
63*	East Ballantrae	Pollen (monolithic samples taken), stratigraphy described	NO	4.10 m	10,350-10,650 yr BP					5 cm	Lees, 1986
64	Delaware Ridge Road	Pollen (monolithic samples taken), stratigraphy described	NO	1.1 m	8160 - 8400 yr BP					5 cm	Lees, 1986
65	Manawatu Gorge	Pollen (monolithic samples taken), stratigraphy described	NO	1.38 m	3430 - 3770 yr BP					5 cm	Lees, 1986
66	West Tamaki River	Pollen (monolithic samples taken), stratigraphy described	NO	2.6 m	770 - 810 yr BP			3.4 mm per year		5 cm	Lees, 1986

Table 3.1. Palaeo environmental studies conducted in and around the North Island, New Zealand, summary facts.

1. Lake Taumatawhana
2. Kaeo Catchment
3. Rangihoua Bay
4. Wharau Road Swamp
5. Panguru Catchment
6. Lake Tauanui
7. Waimamaku Catchment
8. Mangakahia Catchment
9. Tarahoka & Omaia Clearings
10. Maungatapere & Rawhitiroa basaltic cone
11. McEwan's Bog
12. Great Barrier Island – Awana Swamp, Souther Kaitoke, Forsythes Paddock, Harataonga Ba
13. Te Rerenga, Coromande
14. Lake Pupuke
15. Waihi Beach mire, Papmoa mire
16. Kauaeranga Valley
17. Waikato Forest
18. Mayor Island
19. Lake Rotokauri
20. Lake Okoroire
21. Lake Rotomanuka
22. Kohika
23. Rangitaiki
24. Waitomo Catchment
25. Holden's Bay
26. Waipaoa Valley floor
27. Repongaere Swamp
28. Lake Waikaremoana
29. Tiniroto Lake
30. Lake Taupo
31. Mimi Taranaki
32. Lake Rotonuiahe
33. Waitoetoe Taranaki
34. Gibson's Swamp
35. Lake Tutira
36. Mt Taranaki
37. Lake Waiau Swamp
38. Lake Poukawa
39. Lake Horowhenua
40. Lake Waitawa
41. Pauahatanui Inlet
42. Wellington Harbour
43. Continental Shelf – Poverty Bay
44. Lake Papaitonga
45. Waverly Beach
46. Whangape Harbour
47. Lake Namunamu
48. Lake Maungarataiti
49. Lake Pauri
50. Deep Hole, Waikato
51. Deep ocean core easter North Island
52. Otaki Swamp, Horowhenua
53. Lake Alice, Rangitikei
54. Colenso Lake
55. Lake Taupo Central Nort Island
56. W4 East Coast Floodplain
57. MD972122 Ocean Core Shelf
58. MD972121 Ocean Core
59. P69 Marine Core south eastern North Island
60. Lake Maratoto
61. S803 Marine Core Bay of Plenty
62. Kaiparoro Clearing Tararua Range
63. West Ballantrae & East Ballantrae
64. Delaware Ridge Road
65. Manawatu Gorge
66. West Tamaki River

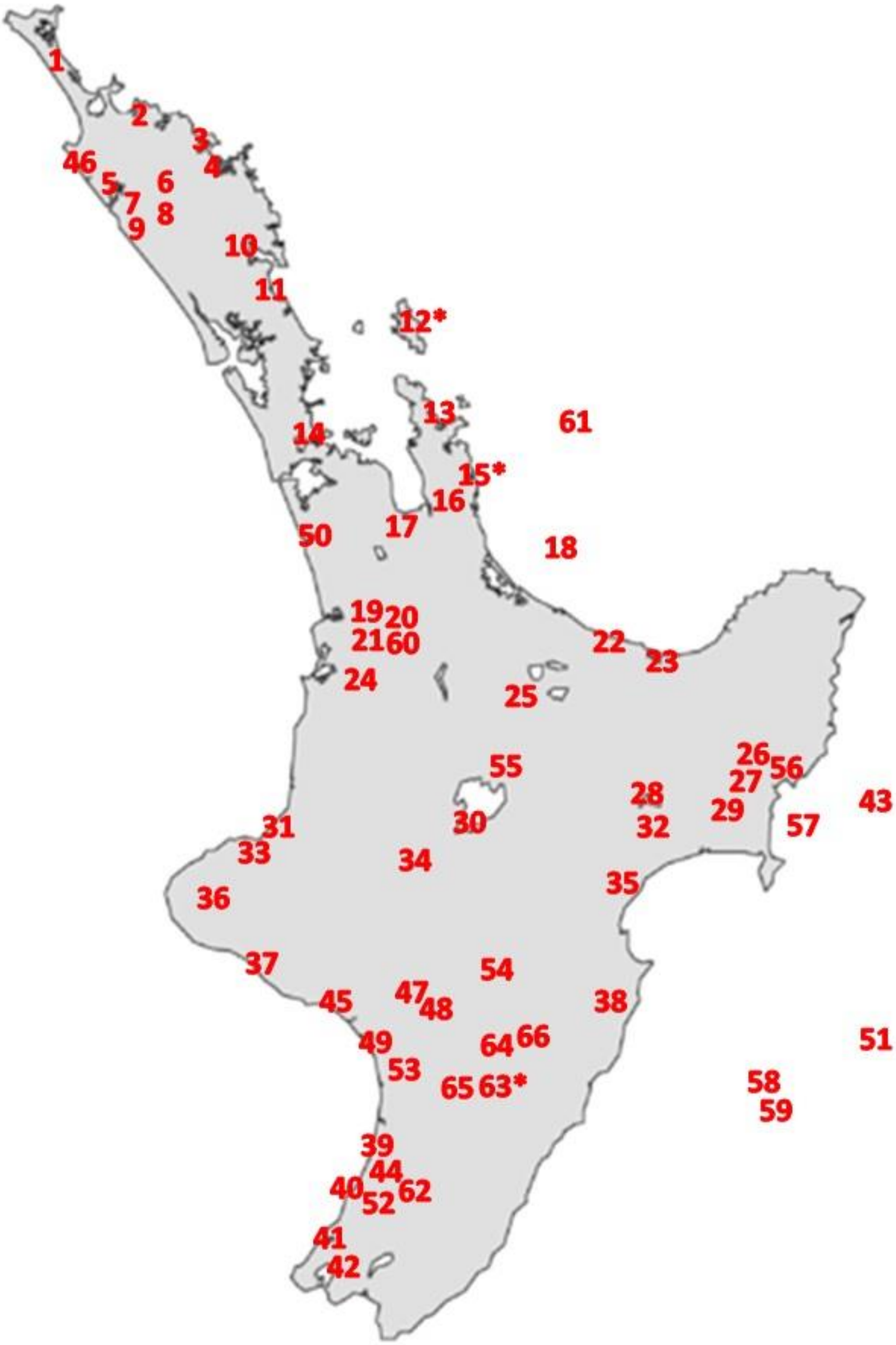


Figure 3.1: Approximate locations of studies that reconstructed the past environment in the North Island, New Zealand

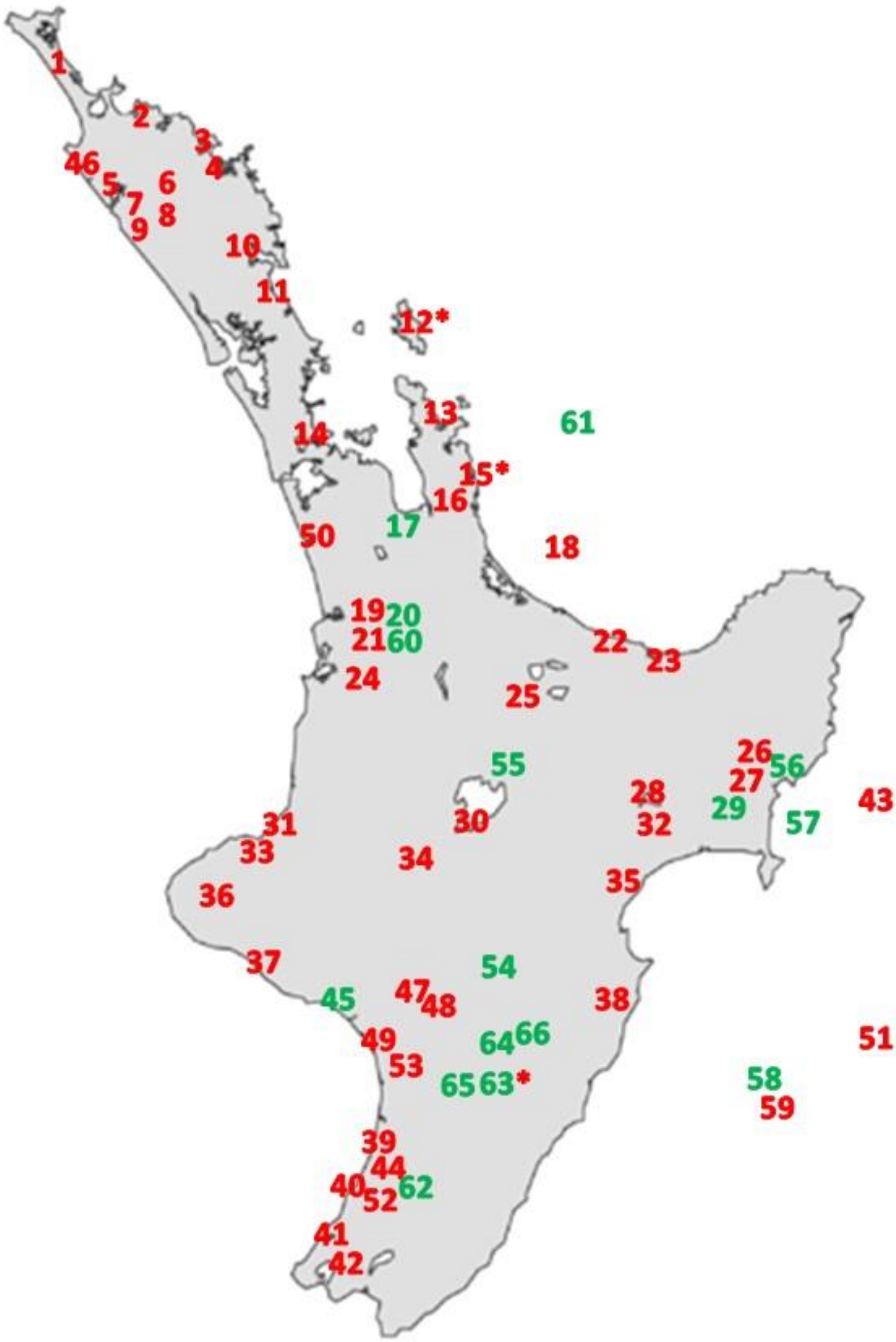
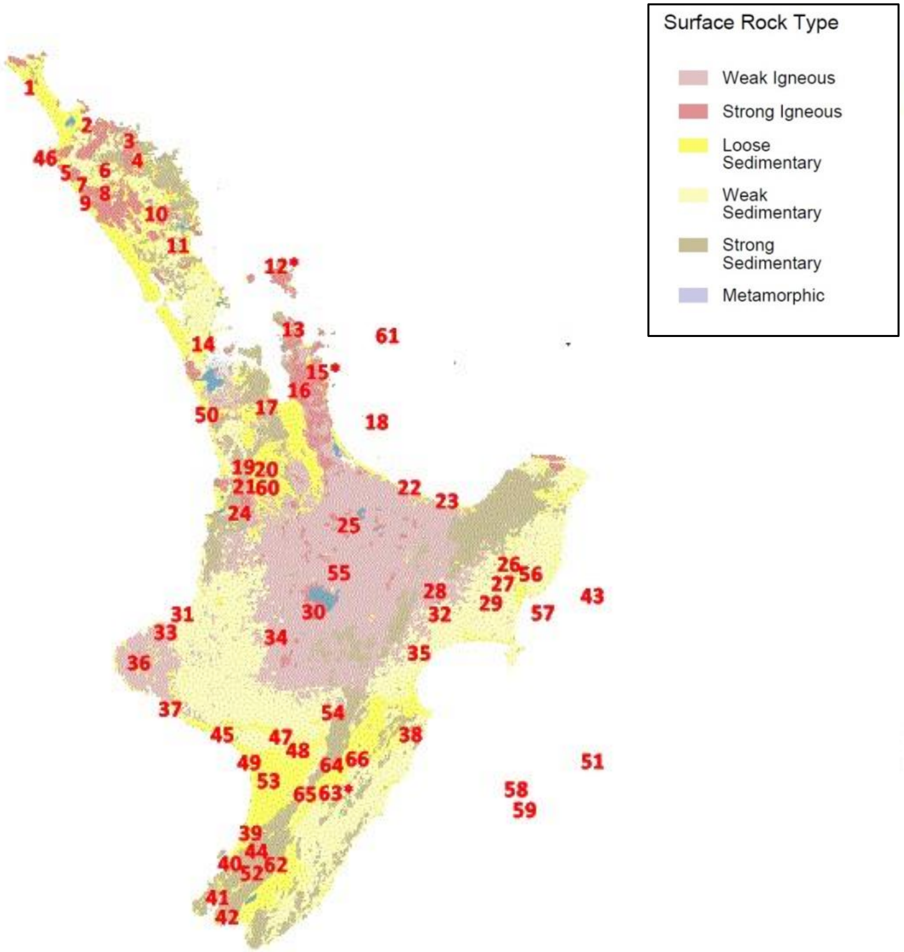


Figure 3.2: Sites that showed anthropogenic disturbance (red) and sites that did not (green).



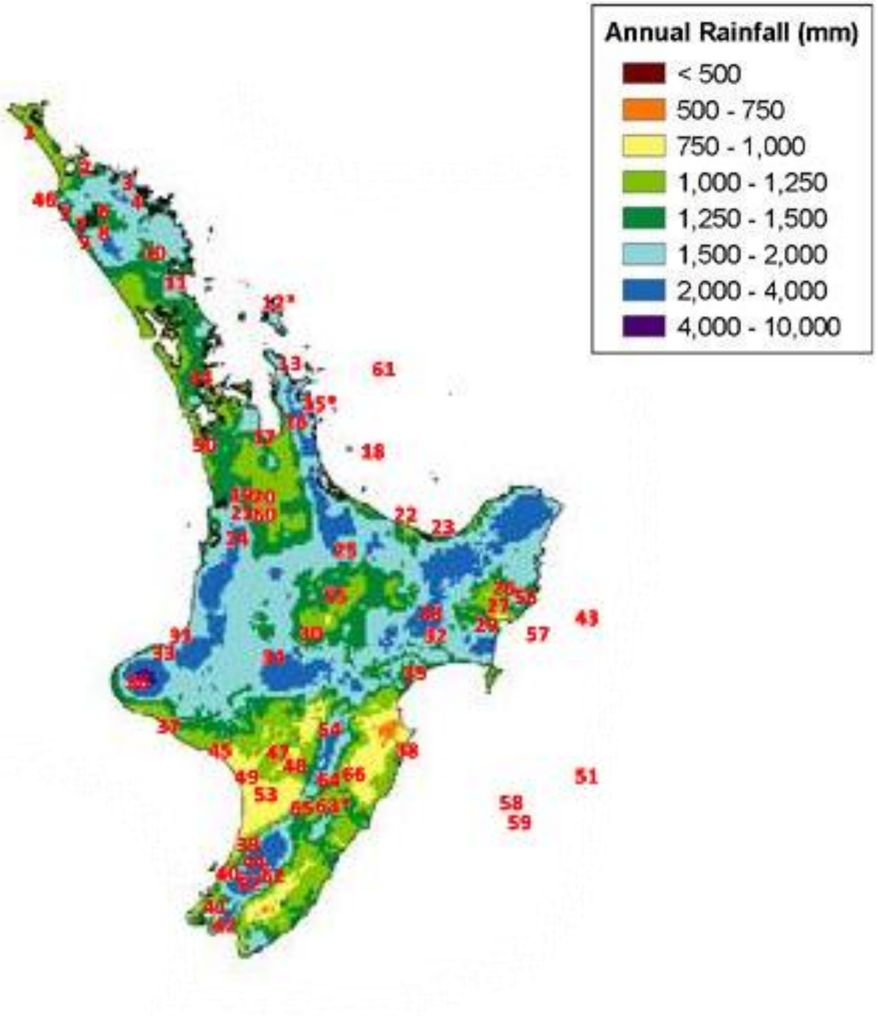


Figure 3.3 (left): Sites with the underlying geology, as described from Landcare Research (2015).

Figure 3.4 (right): Sites with the Annual Rainfall from NIWA (2015).

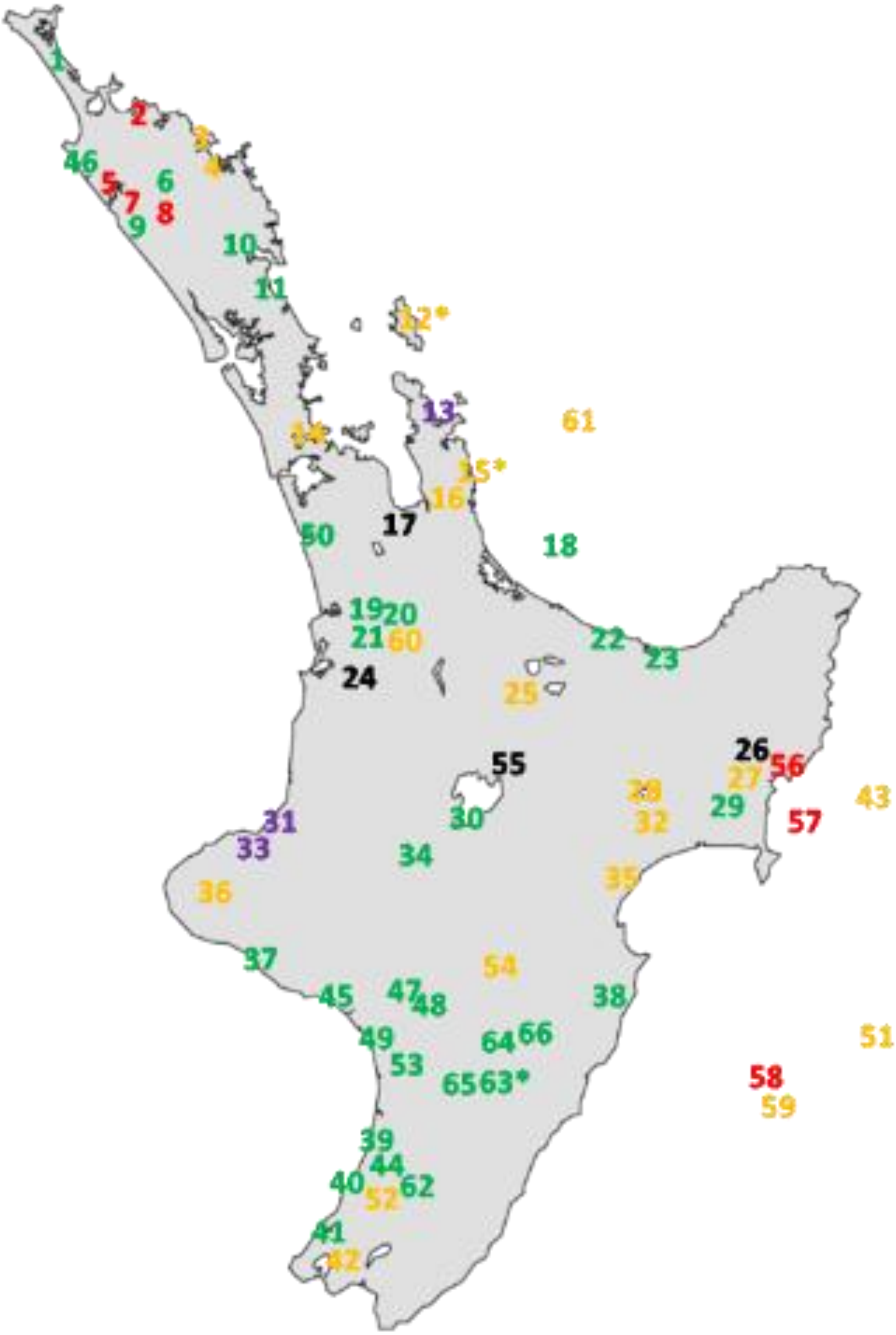


Figure 3.5: Sites colour coded based on the main proxy type used (refer to Table 3.2).

Table 3.2: Broad categorises used to group the environmental reconstructions and should be used in conjunction with Figure 3.5.

Colour of Site	Main Proxy Type	Description
Green	Pollen	Using pollen as either the only proxy and/or also combining with charcoal and radiocarbon dating
Red	Sediment	Using sediment analysis such as Particle Size Analysis (PS), Xrays, core stratigraphy description, supplemented by radiocarbon dating in some cases
Purple	Animal fossils	Using any type of animal to determine what was present or reconstruct the environmental conditions (e.g. rat bones, beetles)
Black	Other	Uncommon proxy not described broadly above (e.g. aerial photography, modelling relationships)
Orange	Multiproxy	Using a combination of at least two of the described proxies above (e.g. pollen analysis and sediment analysis)

3.3.1 Disturbance Studies

In Figure 3.1 the studies compiled are displayed with their approximate location on the North Island of New Zealand. Over 60 case study sites have been compiled, covering a large portion of the North Island. Figure 3.1 illustrates that there are key areas that have had multiple studies conducted, particularly the east coast and in the north. Areas that appear to be somewhat neglected are the south east, north east of Gisborne and parts of the central North Island. In comparison to the South Island study of McWethy *et al*. (2010), there are firstly significantly more studies conducted across the North Island than the South. This may be due to the easier accessibility of the North Island sites compared with the South Island, as the latter has greater terrain boundaries to cross (Alloway *et al*. 2007). Also McWethy *et al*. (2010) focused solely on charcoal and pollen records obtained from lakes; this review encompasses all types of proxies used to reconstruct the past environments, significantly broadening the range of available data.

Figure 3.2 illustrates the sites that showed evidence of any human disturbance, either of Polynesian or European origin. Of the total sites, 15 did not show any evidence of anthropogenic activities in the published record. Interestingly, many of these sites with no evidence are situated next to sites that did find evidence of human disturbance. Newnham *et al*. (1989) illustrated this perfectly with palynology results from three lakes: Lakes Rotokauri, Okoroire and Rotomanuka. Situated in the Waikato lowlands, cores were extracted from these lakes, and pollen samples were extracted at 10 cm intervals to reconstruct the environment, with tephra chronologies used for age control over. All three cores gave a history dating back to 18,000 cal. yr BP. However, only Lakes Rotokauri and Rotomanuka showed forest disturbance occurring around 810 +/- 90 cal. yr BP, agreeing with previous work by McGLone (1983) and Hogg *et al*. (1987) in the area. Lake Okoroire had no such disturbance in the top of the core, but this was explained by the difficulty in obtaining samples near the lake bottom interface as the topmost sediments were very sloppy (Newnham *et al*. 1989). This highlights how if the right information is not obtained it can paint a very different picture of what actually happened in the environment. Sampling several lakes in the area of interest enabled a fuller story of the past environment to be told.

As described earlier, one of the limitations of this review centres around case study research aims other than investigating anthropogenic disturbance activities, with the implications being that the techniques used and/or sampling resolution would not necessarily capture the desired time frame. Lees' (1986) work in the lower Ruahine and upper Tararua ranges highlights this. Lees (1986) analysed the stratigraphy of, and pollen samples from, exposed cliff faces. The purpose of the study was to reconstruct post glacial vegetation history, as there was a lack of knowledge in this region. This was of particular interest due to the acceleration of erosion in the area. Therefore samples were taken at 5 cm intervals but not to the topmost part of the soil. It was noted that the deterioration of climate causing increased storminess led to the upper forest being replaced with *Olearia colensoi* scrub, and Lees (1986) could not reliably find a link between the decline in *Weinmannia racemosa* with the human introduction of the possum to the area. If further subsamples were taken at finer intervals, they may have potenitally captured the continued decline in response to human occupation, if it was in fact there. This does limit what we can infer from the studies collated here, and highlights the limitations present that need to be understood when analysing disturbance across the North Island from this collection of palaeoenvironmental records.

3.3.2 The influence of Geology on Disturbance

Figure 3.3 compares the sites of disturbance with the underlying geology of the North Island. This was done to determine if the geology may have impacted the magnitude, frequency or spatial patterns of disturbance in the North Island. The majority of the studies were conducted at sites with loose or weak sedimentary rock from the Tertiary period (Landcare Research, 2015). Sedimentary rocks are formed from the deposition of sediment eroded or weathered from a source before being deposited and compacted (Berryman, 1988). Due to frequent tectonic activity in New Zealand, sedimentary rock which accumulated on the sea floor has been rapidly uplifted, tilted, compressed and generally deformed, creating the diverse geological features observed today (Berryman, 1988; Adams *et al*. 1994). This rock type makes up a large proportion of the underlying geology of New Zealand as observed in Figure 3.3. Combined with the unique climate, these rocks are easily eroded, with the sediment mobilised and deposited in low lying areas. Because of the ease of which this rock type can degrade, it in itself is a great proxy for monitoring disturbance in sedimentary basins through changes in sedimentation rates.

What has been highlighted though is areas on loose sedimentary rock tend to have long lasting impacts following human disturbance. For example, many studies have been conducted in the Hawke's Bay region (e.g. Campbell *et al*. 1973; McGlone, 1983; Wilmshurst *et al*. 1999; Li *et al*. 2014) have found that, following anthropogenic activities such as deforestation and land conversion, changes in the natural sedimentation rates have occurred. Wilmshurst (1997) found an increase of the sedimentation rate at Lake Rotonuiaha from 1.7 mm per year prior to any human disturbance, to 2.6 mm per year following Polynesian settlement, and a further increase to 10.5 mm per year once Europeans began forest clearance. Because of the susceptibility to erosion and the ease of mobility of sedimentary rock, any type of disturbance can have a long lasting impact that will take hundreds, if not thousands of years to correct, as seen from natural, climate-driven disturbances to the environment (e.g. McGlone *et* al. 2001; Gomez *et al*. 2004).

This is not to say that geology is the most influential factor; as illustrated, there were studies showing change on weak and strong igneous rock types. Studies conducted in the central North Island and parts of the northern plateau showed evidence of disturbance (e.g. Elliot *et al*. 1995; Ogden *et al*. 2003; Gates, 2013; Richardson *et al*. 2014; see Table 3.1). Furthermore when comparing with McWethy *et al*. (2010) the case studies used were also across a variety of surface geologies, including sedimentary but also metamorphic rock and still have had lasting impacts on the vegetation history following the initial disturbance. Any type of rock, following deforestation of its surface, is prone to erosional and depositional processes once exposed. The underlying rock type may be more susceptible to erosional processes, allowing easier identification of disturbance through greater changes in the rate of sedimentation as observed in places such as Hawke's Bay and Gisborne (Wilmshurst, 1997; Eden & Page, 1998; Reid & Page, 2002). However the sites compared and contrasted here do not indicate that the underlying geology is the key controlling factor impacting the magnitude and locations of disturbance in the North Island, but may be a contributing factor.

3.3.3 Rainfall and Disturbance

Figure 3.4 illustrates the annual rainfall across the North Island based on rainfall records from 1971 to 2014. Rainfall does not appear to restrict or enhance the potential or magnitude of disturbance in the North Island. McWethy *et al*. (2010) observed in higher altitude (>600 masl), wetter settings (> 1600 mm per year) that the impact of human-induced forest fires had substantially less impact during the Initial Burning Phase (i.e. arrival of first Polynesians to an area). This is challenging to determine if this is the case in the North Island. In the South Island there is a greater variation of rainfall distribution due to the Southern Alps causing a distinct orographic and rain shadow effect across the west to east coast. Comparatively, the North Island also has an orographic rainfall affect, but to a lesser extent. There are still distinct areas receiving more rainfall; the central North Island and mountain ranges from the Tararua to the Kaweka mountain ranges, and the Coromandel Peninsula receive greater than 1500 mm per year. The majority of studies compiled for this review were not at high elevations, with the highest located in the Ruahine Ranges (Colenso lake, >800 masl) but were spread across a range of high and low rainfall regions. For example, pollen records from Lake Waikaremoana, which receives over 2000 mm per year in rainfall, showed evidence of vegetation disturbance following settlement of Polynesians and Europeans distinctly (through increase in charcoal, *Pteridium* and *Poaceae* species) but has not continued to be overrun by exotic species in the last century. This initially looks to support one of McWethy *et al.* (2010) conclusions, but when put into context of what has happened to the area around Lake Waikaremoana in the last century it may not be so. The lake is a part of a National Park, meaning forest clearance (and subsequent large scale human activities) is restricted to prevent further disturbance and to preserve the environment. Therefore though initially disturbed, it has not continued to be so due to continued human intervention in the form of restricting vegetation clearance.

This does however support another one of McWethy *et als* (2010) observations; sites situated away from human travel ways and long term settlements showed less disturbance and also shorter lasting impacts. This is supported by studies in the North Island that were situated far from human intervention, and surprisingly showed little to no evidence of disturbance (e.g. Lowe *et al.* 1980; Leathwick & Mitchell, 1992; Rogers & McGlone, 1994);. For example, MacDonald-Creevey (2011) constructed a high resolution, multiproxy reconstruction on Lake Colenso, situated in an isolated area of the northern Ruahine mountain range, away from traditional Polynesian trackways. Over the 1800 year span of the extracted core, there was no evidence for anthropogenic activities in the vicinity of the site, even though this time period is known to have human settlement across the North Island. Remote sites are therefore less likely to be disturbed.

In comparison to the South Island, the disturbances, such as land clearance through vegetation burning, construction of large scale settlements and changes to land use observed in the North Island have had longer lasting impacts. This is mainly due to the increase human presence in the North Island (Anderson, 2003) in comparison to the South Island. This has resulted in greater deforestation (McGlone, 1983) and land use changes that have caused in many cases irreversible changes to the landscape. Therefore of the conclusions drawn by McWethy *et al*. (2010) and comparing the rainfall across the North Island, this does not appear to be a controlling factor of the amount nor the magnitude of disturbance occurring. It appears the longevity, magnitude and amount of the disturbance is more tied to the ongoing and increased human activity in an area. Where humans have retreated or diminished from the environment has shown varying results of recovery to pre-human activities.

3.3.4 Proxies used for determining Disturbance

Figure 3.5 display the type of proxies used in the studies reviewed. Refer to Table 3.2 for the description of the categories used to describe the main types of proxies used. Pollen is the most commonly used proxy for reconstructing past environments in these studies. As described earlier (Table 2.1), pollen makes as a very good proxy due to its ability to be preserved in anaerobic environments, its representative nature of what type of vegetation was present, the ability to obtain high resolution reconstructions from it and its relative accessibility of retrieving it from sites (Joosten & de Klerk, 2007). However, like all palaeo reconstruction studies, an age control is required. The most common age controls used have been radiocarbon dating organic material found in samples or using tephra chronology to deduce the time (e.g. Horrocks *et al.* 2007; Wilmshurst *et al*. 2008; Striewski *et al*. 2009; Li *et al*. 2014).

While pollen is very valuable as a proxy in disturbance studies, as it can disentangle disturbances from natural from anthropogenic with high certainty (e.g. Horrocks *et al*. 2001; Odgen *et al*. 2003), there are other techniques that can be utilised alongside or independently from it. Other techniques are also very important, especially those which allow investigation of sedimentation rate through Particle Size Analysis and core stratigraphy analysis. Multiple studies have observed the trend of increased influx of sediment into lakes, swamps and surrounding floodplains after deforestation has occurred, resulting from once stable slopes becoming more susceptible to landsliding, aeolian and fluvial erosion (Glade, 1998; Glade, 2003; Brierley & Fryirs, 2005; Gregory, 2006; Richardson *et al.* 2013). This has led to higher sediment accumulation rates after human settlement which provides evidence of disturbance independent of pollen data. Table 3.3 adapted from Glade (2003) summarises the evidence of increased sedimentation rates following human arrival. This is particularly useful for New Zealand given susceptibility of weak sedimentary rocks to erosion. This can be used to calculate sedimentation rates, which is a useful tool to determine how the landscape has been disturbed and also pinpointing the change when combing with other proxies, such as pollen analysis.

Location	European (pasture) rate (mm $year^{-1}$)	Polynesian (scrub-fern) or pre-Polynesian (forest) rate (mm $year^{-1}$)	Factor of Increase
Whangape Harbour (estuary)	1.7-4.6	0.1-0.5	9.2-17
Repongaere (swamp)	3.6	0.3	12
Poverty Bay (continental shelf)	3.7	0.3	12.3
Lake Tutira (freshwater lake)	14.0	2.1	6.7
Wellington Harbour (near coast)	38.2	2.1	18.2
Abel Tasman (coastal wetland)	1.6-2.7	0.5-1.7	1.6-3.2

Table 3.3: Evidence of increased sedimentation rate following European occupation

Adapted from Glade (2003).

Subfossil vertebrate remains are also quite rare in environmental reconstructions in the North Island, and in general for the whole of New Zealand, when compared with other parts of the world. New Zealand has few endemic and exotic mammal species that are appropriate for radiocarbon dating (Worthy, 1999). Polynesians brought the Pacific rat to New Zealand but finding their remains is difficult, and even more challenging finding well preserved ones (e.g. Sutton *et al*. 2008; Wilmshurst *et al*. 2008).

Trace element analysis has only been utilized in six of the studies compiled but it can be very useful for inferring human arrival to an area (refer to Table 3.1). Elliot *et al*. (1997) found distinct peaks in potassium and sodium concentration coincided with a change in the stratigraphy of three core samples from Northland. This represented a rapidly increased rate of inwashed material to the swamp from soil freshly exposed following deforestation by Polynesian and European settlers. World-wide, the technique has been used particularly effectively to show the impact of European activities such as mining on the environment (e.g. Macklin *et al*. 1994; Hudson-Edwards *et al*. 1997; Craft & Casey, 2000, Roulet *et al*. 2000). This would be applicable in the New Zealand setting as though while our mining history is shorter than those on the international scale, due to the geology and climatic setting of New Zealand, we would expect to see significant changes as a result of this human activity (e.g. Craw & Chappell, 2000).

As mentioned previously, because multiple palaeo environmental reconstruction proxies were included, more sites were analysed and compiled in this review in contrast to the summary South Island study by McWethy *et al*. (2010). This is also due to the focus of their study, in determining the disturbance following the Initial Burning Phase of Polynesian settlement which needs to be taken into account when comparing the North to the South Island in regards to disturbance. Combining more diverse proxy studies that have been conducted in the South Island may reveal more results agreeing with the conclusions stated by McWethy *et al*. (2010) or might tell a different story all together. Using multiple proxies in the North Island has shown that disturbance has occurred following human occupation to an area, with the different type of proxy not bringing bias to the results, as shown by studies that have used a combination of proxies (e.g. Newnham *et* al. 1995; Elliot *et al.* 1997; Wilmshurst *et al*. 1999) but further validates the conclusions derived from the results. Multiproxy studies are therefore more preferable and to a degree more reliable than those based on limited proxy data.

3.4 Summary

The North Island disturbance review revealed that a wealth of knowledge of the previous environmental landscape of this part of New Zealand has been well documented, particularly in regards to the arrival and impact of humans. When comparing the underlying geology and rainfall of the North Island in regards to disturbance, there does not seem to be a clear pattern. Many studies were conducted on weak or loose sedimentary rock, which would show a greater change due to the sensitive nature of the rock to erosion and therefore human activities such as deforestation and land use conversion. However studies on igneous rock also showed evidence of impact, in some cases large scale amount (e.g. Elliot *et al*. 1997; Richardson *et al*. 2014). The rainfall patterns across the North Island also did not tie in with areas that observed disturbance, as was noted in the South Island by McWethy *et al*. (2010). When comparing and contrasting the research, the key factors determining the disturbance appears to be the activities and use by humans. Places that became permanently settled by both Polynesians and Europeans were disturbed and have had long lasting changes (e.g. Newnham *et al*. 1995; Dickson, 1997; Wilmshurst *et al*. 1999; Purdie, 2004). Whereas places that were settled initially but are no longer actively inhabited or transformed into a different landuse practice (e.g. agriculture) at present are slowly recovering to a state closer to their prehuman condition (e.g. Newnham *et* al. 1998; Wilson, 1999). This is supported by McWethy *et al*. (2010) work on the South Island disturbance, showing that there is a link between the two islands of New Zealand. Furthermore what is also very important to note is the limitations of the above results, with the resolution and purposes of the studies impacting the results as well as the length of record may not contain the time frame of interest. This review sets the foundation for further research to be added to it to allow continued analysis of the patterns and distribution of disturbance across New Zealand.

Chapter 4: Case Study of the Coromandel

Having established the spatial and magnitude of disturbance in the North Island, New Zealand, and reviewing the type of proxies has highlighted the use of sedimentology and geochemistry as useful tools to identify the nature and timing of disturbance in the New Zealand environment. This case study provides the first quantitative assessment of floodplain response to the impact of historic fold mining in the Coromandel Peninsula, using both sedimentology and geochemistry. The case study assesses the nature and the longevity of disturbance associated with historic mining in two contrasting catchments located in the south (Ohinemuri) and north (Kuaotunu) of the Coromandel.

4.1 Environmental History

4.1.1 Geology

The Coromandel Peninsula is located in the north west of the North Island, New Zealand (see Figure 4.1). The area is part of the late Cenozoic Hauraki Volcanic Region of New Zealand, with the Coromandel Peninsula being the central subaerial sector of the Coromandel Volcanic Zone which was a precursor to the Taupo Volcanic Zone (Adams *et al*. 1994). The area is uplifted and tilted to the east (Healy *et al*. 1981).The beginning of volcanism has been dated back to the early Miocene based on sediments corresponding to the Colville Formation of the Waitemata Group, containing volcaniclastic mass flows. The last period of volcanic activity in the Coromandel ended in the Pliocene, with the last andesitic eruptions occurring in the Late Pliocene (Black & Skinner, 1979; Brathwaite *et* al. 1989; Adams *et al*. 1994). The stratigraphy of the Coromandel Peninsula is comprised of a basement of Mesozoic greywacke, with the oldest rocks dating back to the Late Jurassic, overlain by Late Cenozoic igneous rocks, mainly andesites and rhyolites, due to the volcanic nature of the area (Williams, 1974; Craw & Chappell, 2000; Adams *et al*. 1994). The basement greywacke rocks are cut by hydrothermal vein systems containing varying amounts of gold, silver and other base metals within quartz veins, with the intensity of the hydrothermal vein systems greatest in the top 50 m (Brathwaite *et al.* 1989; Craw & Chappell, 2000).

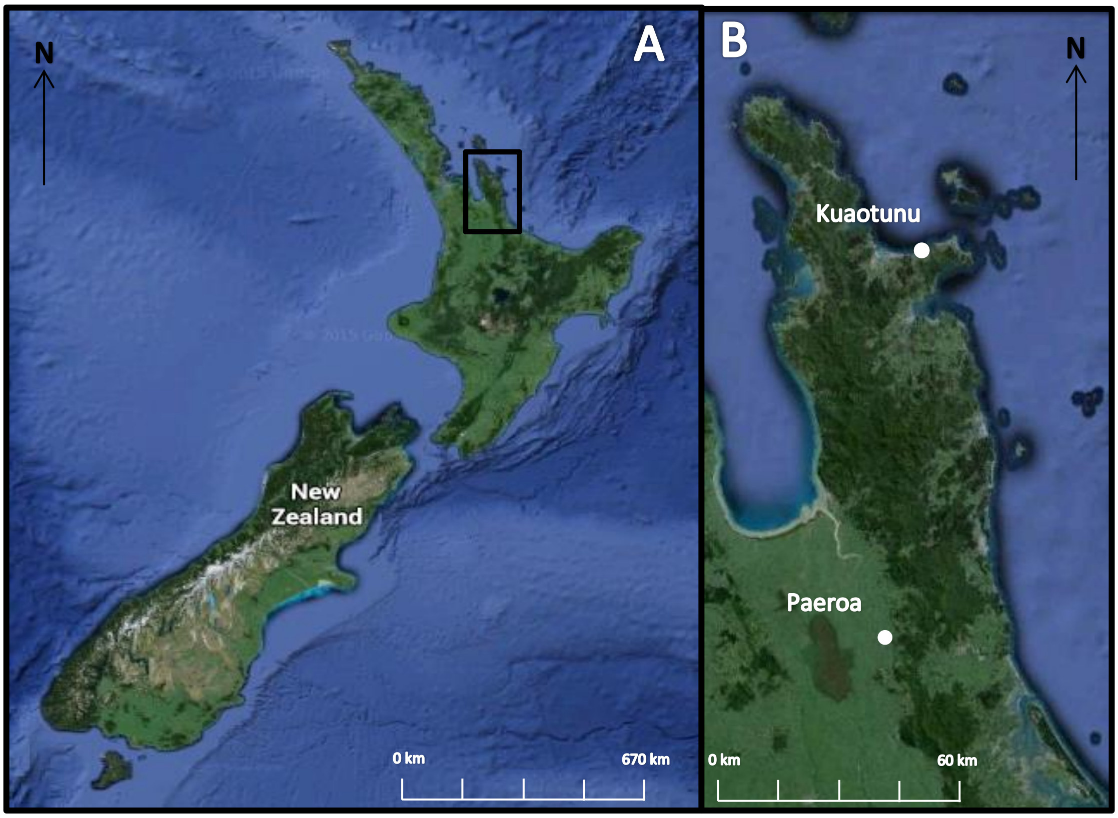


Figure 4.1: A) Location of the Coromandel Peninsula in relation to the rest of New Zealand. B) Coromandel Peninsula with two key townships for this study.

There are two main theories, not necessarily mutually exclusive, as to why gold and silver deposits are present in the Coromandel: that gold was brought up by thermal action from the underlying Tertiary strata; or that the mineral was derived from the overlying volcanics (Downey, 2002**;** Adams *et al*. 1994; Brathwaite, 1989). Geochronological work has supported the thermal action theory, illustrated by the underlying rock being cut by structurally controlled hydrothermal veins that contained gold and other base metals within quartz (Craw & Chappell, 2000; Adams *et al*. 1994). However, continued mining drilling did not discover larger, richer gold-content quartz as would be expected, which had been found in other parts of New Zealand mining regions that are volcanic, if the thermal action theory occurred in this region (Downey, 2002). Brathwaite *et al*. (1989) proposed a combination of the two theories, as they associated base-metal mineralisation (i.e. the formation of gold and silver deposits) to differing styles of volcanism and the intensity of hydrothermal alteration based on the mineralised volcanic sequences, geochronological dating and geochemistry. This appears to support the majority of work prior to and continued since this publication (e.g. Black & Skinner, 1979; Adams *et al.* 1974; Craw & Chappell, 2000).

4.1.2 Geomorphology, climate and Vegetation

Due to active volcanism and tectonism in the wider region, the Coromandel has steep, irregular topography with altitudes reaching up to 800 m (Hume & Dahm, 1991). This has resulted in steep, incised river valley systems that, in conjunction with a high annual average precipitation of 3000 mm yr^{-1}, can produce flash floods (Ross *et al*. 1994). Up to 550 mm of rainfall can fall within a 24 hour period (Mead & Moores, 2005). When high velocity easterly and north-easterly winds associated with storm events occur it can result in torrential orographically-induced rainfall, increasing erosion within unstable catchments (Bradshaw, 1991). Historically, the wettest month on record is July averaging 175 mm of rainfall, with September receiving the least. The coolest recorded temperature average is also in July, averaging -1 degrees Celcius with January receiving the warmest of 28 degrees Celsius historically (Metservice, 2014).

Prior to human settlement, the vegetation of the Coromandel consisted of a mixture of podocarp-hardwood forest, with emergent *Dacrydium cupressinum, Metrosideros robusta, Agathis australis* as well as other *Dacrycarpus* and *Phyllocladus* species. Low-lying areas also had *Libocedrus, Podocarpus, Griselina* and *Rhopalostylis* species present (Byrami *et al*. 2002; see Figure 4.2 A). At present, there are still remnants of a mixed hardwood-podocarp forest but severely reduced in size, with shrubland species such as *Leptospermum scoparium, and Coriaria arborea* abundant in low-lying areas, as well as grasses dominating areas converted for farming purposes further inland (Newnham *et al.* 1995; Byrami *et al*. 2002; see Figure 4.2 B).

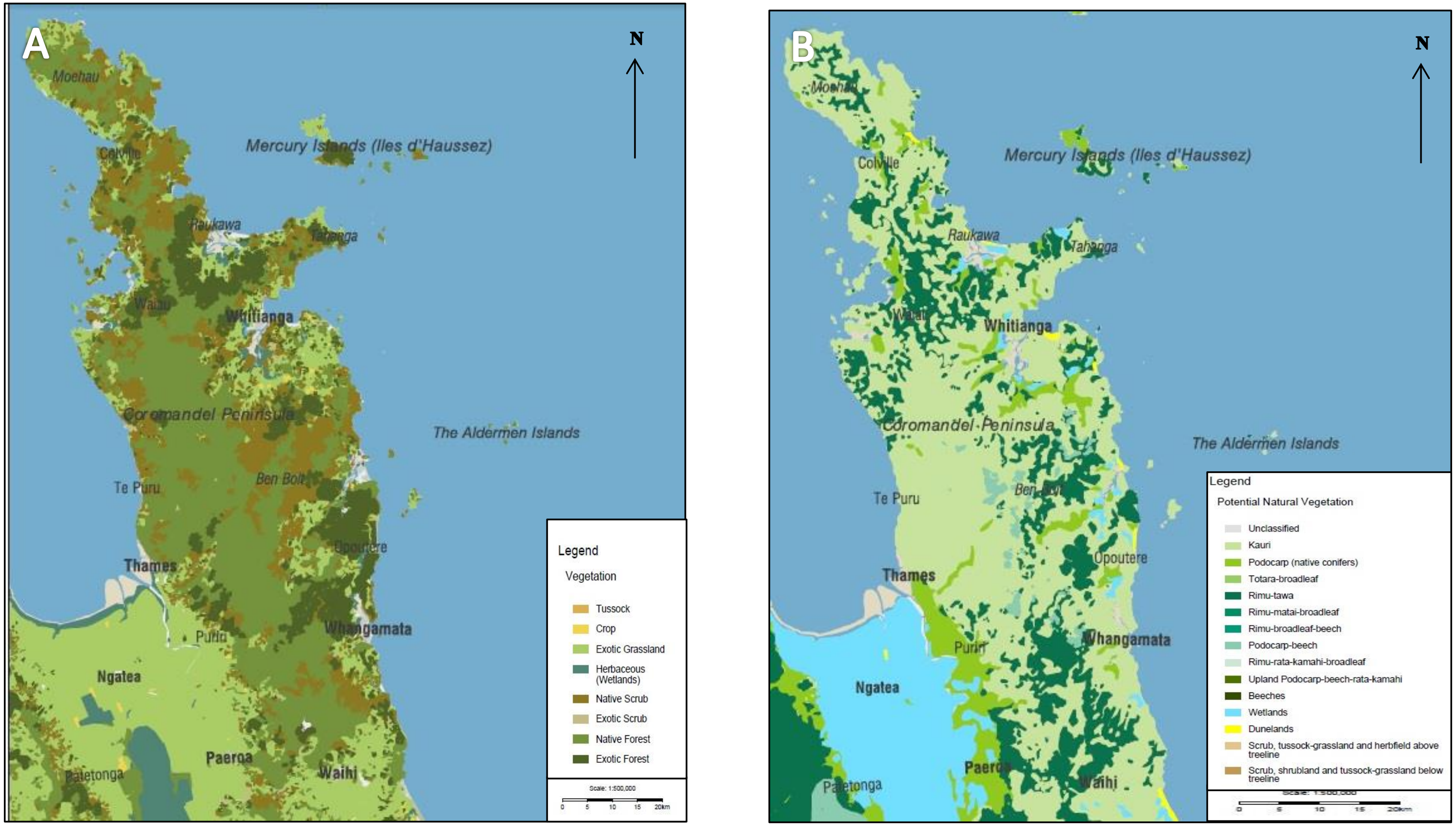


Figure 4.2 A: Present day vegetation across the Coromandel Peninsula. Adapted from Landcare Research (2016).

Figure 4.2 B: Potential Natural vegetation prior to human settlement across the Coromandel Peninsula. Adapted from Landcare Research (2016).

4.2 Anthropogenic History

The Coromandel was occupied by Maori before the arrival of Captain James Cook in 1769. Captain Cook led the way for European immigration (Salmon, 1963; Moore & Ritchie, 1996; Heritage New Zealand, 2009; see Figure 4.3). By the early 1830s the Coromandel became settled in response to the establishment of the Kauri felling industry. These trees were ideal for harvesting as they produced a large amount of timber free of knots,and naturally resistant to many types of rots and was particularly useful for creating sturdy homesteads (Ferguson *et al*. 1910; Hayward, 1978; Heritage New Zealand, 2009; Weston, 1927). During the end of the Kauri trade boom in the mid-1800s the first gold in New Zealand was discovered in the Coromandel, triggering the gold rush for the entire country and bringing in more settlers to the Peninsula (Weston, 1927; Ferguson *et al*. 1910). From the 1870s to the 1930s mining boomed, before declining. A resurgence of mining occurred post-1980s with some large mines still in operation today (Newmont, 2015). At present tourism and associated accommodation services, specifically ecotourism, is the largest industry operating in the region with agriculture, specifically dairy farming, prominent further inland (Statistics New Zealand, 2015).

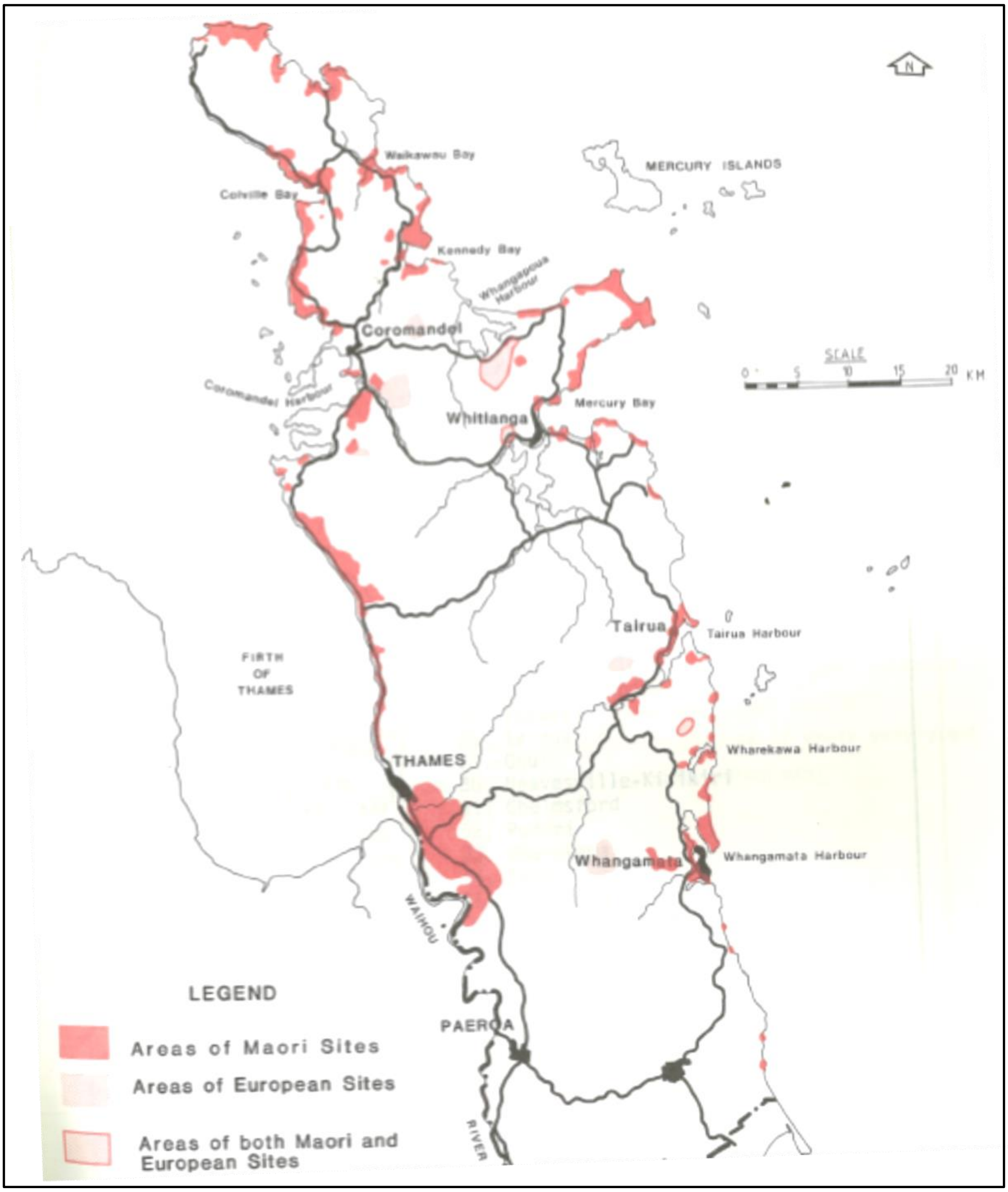


Figure 4.3: Areas of the Coromandel Peninsula that were occupied by Maori and Europeans, based on archaeological sites identified from first Maori settlement to 1980. From Gabites *et al*. (1984).

4.3 Gold Mining History

Gold was first discovered in New Zealand in 1852 by Charles Ring in Driving Creek, north-east of the township of Coromandel (Weston, 1927; Salmon, 1962; Paul, 2001). From then on into the early 1930s the Coromandel Peninsula became a thriving gold mining destination, with hundreds of claims made in over 47 gold and silver deposit sites. Initially, it took nearly a decade from the first discovery of gold before mining production significantly increased in the Coromandel, due to the majority of the land being in Maori ownership (Moore & Ritchie, 1996; Salmon, 1963). This resulted in some land disputes and a generally unfriendly attitude between the Polynesians and European slowing the mining progress. This changed in 1861 when a large discovery of rich auriferous quartz was found over 29 acres in the Kapanga Area. This increased efforts to mine and to continue mining explorations and thus led to the significant amount of mining that occurred during this time period (Salmon, 1963). If it had not been for the gold rush of 1861 it has been speculated that the country's growth would have been set back by as much as 50 years, as it allowed for the finance of the farming industry (Moore & Ritchie, 1996), which is currently New Zealand's largest industry (Statistics New Zealand, 2015).

4.4 Kuaotunu and Paeroa Mining History

For the purpose of this study, two areas were selected for coring to determine the impact mining and related land clearance, had on floodplain sediment and sedimentation rates in the area. The areas chosen were the Kuaotunu and Paeroa areas, the latter being a part of the wider Ohinemuri floodplains, which has a long history of mining, as discussed in this section (Waihou & Ohinemuri Rivers, 1910).

4.4.1 Kuaotunu

The Kuaotunu area was one of the most northern mining fields in New Zealand (Moore & Ritchie, 1996; see Figure 4.4). The main stream flow from the <20 km^2 catchment is to the west of the Kuaotunu township and out into the eastern Hauraki Gulf. It is a relatively short but steep catchment and experiences flash flooding, particularly during the passage of northerly weather systems in mid to late summer (Waikato Regional Council, 2015). Gold was first discovered here in 1889 by Alexander Peebles in Bald Hill (Salmon, 1963). Over 15 different claims were made over a relatively small area in Kuaotunu (see Figure 4.5), with the largest in physical excavation size and extraction of material being the Try Fluke Claim.

This comprised an outcrop of ore which was first mined in June 1890 and by October of that same year 1408 tonnes of quartz had been crushed creating a return of 3308 oz. bullion that had a value of £8766 (Salmon, 1963).

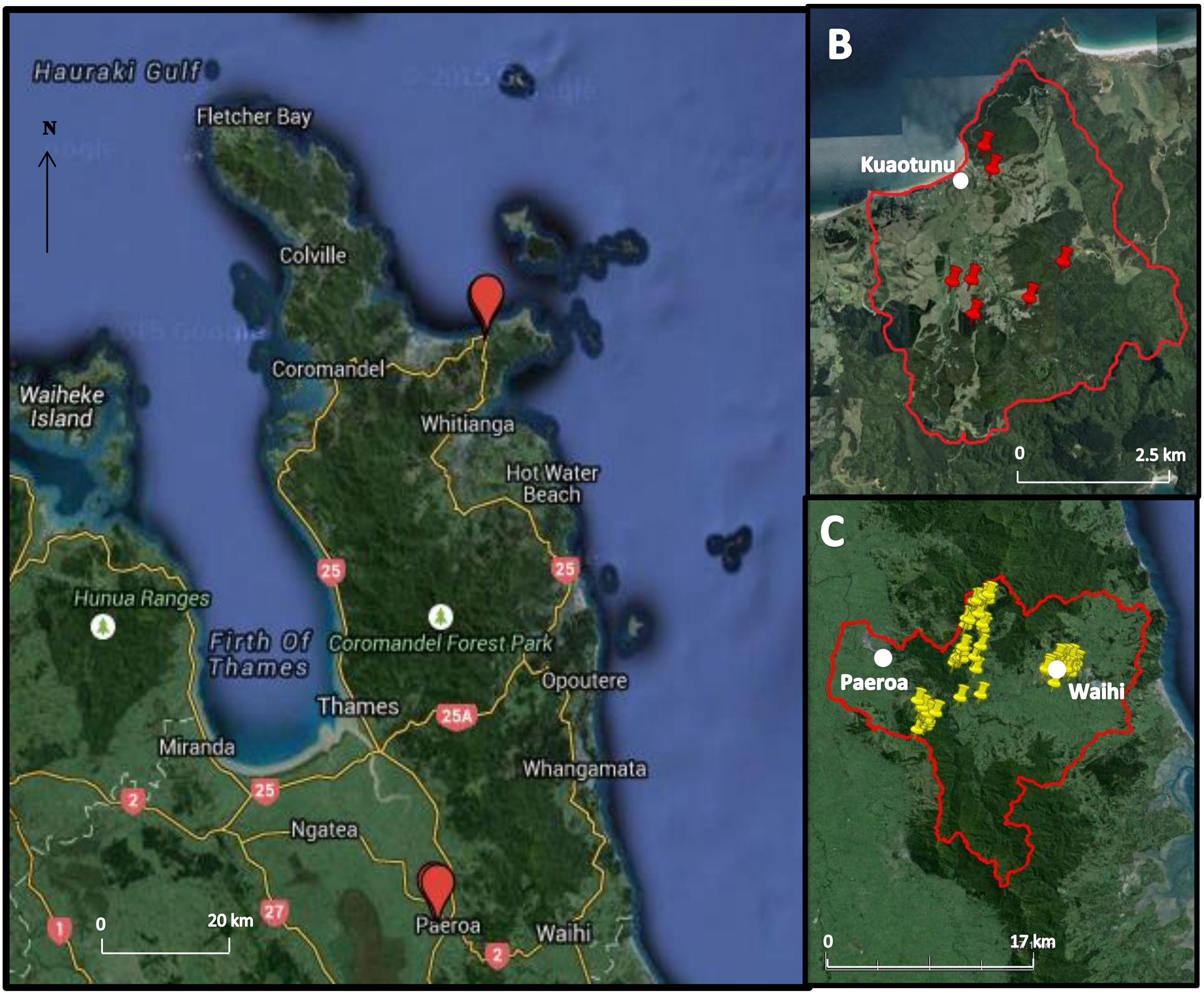


Figure 4.4: A) Location of the Kuaotunu and Paeroa areas where mining took place directly or upstream of the townships (red markers). B) Kuaotunu Catchment with key mining locations (red pins). C) Ohinemuri Catchment with key mining locations (yellow pins).

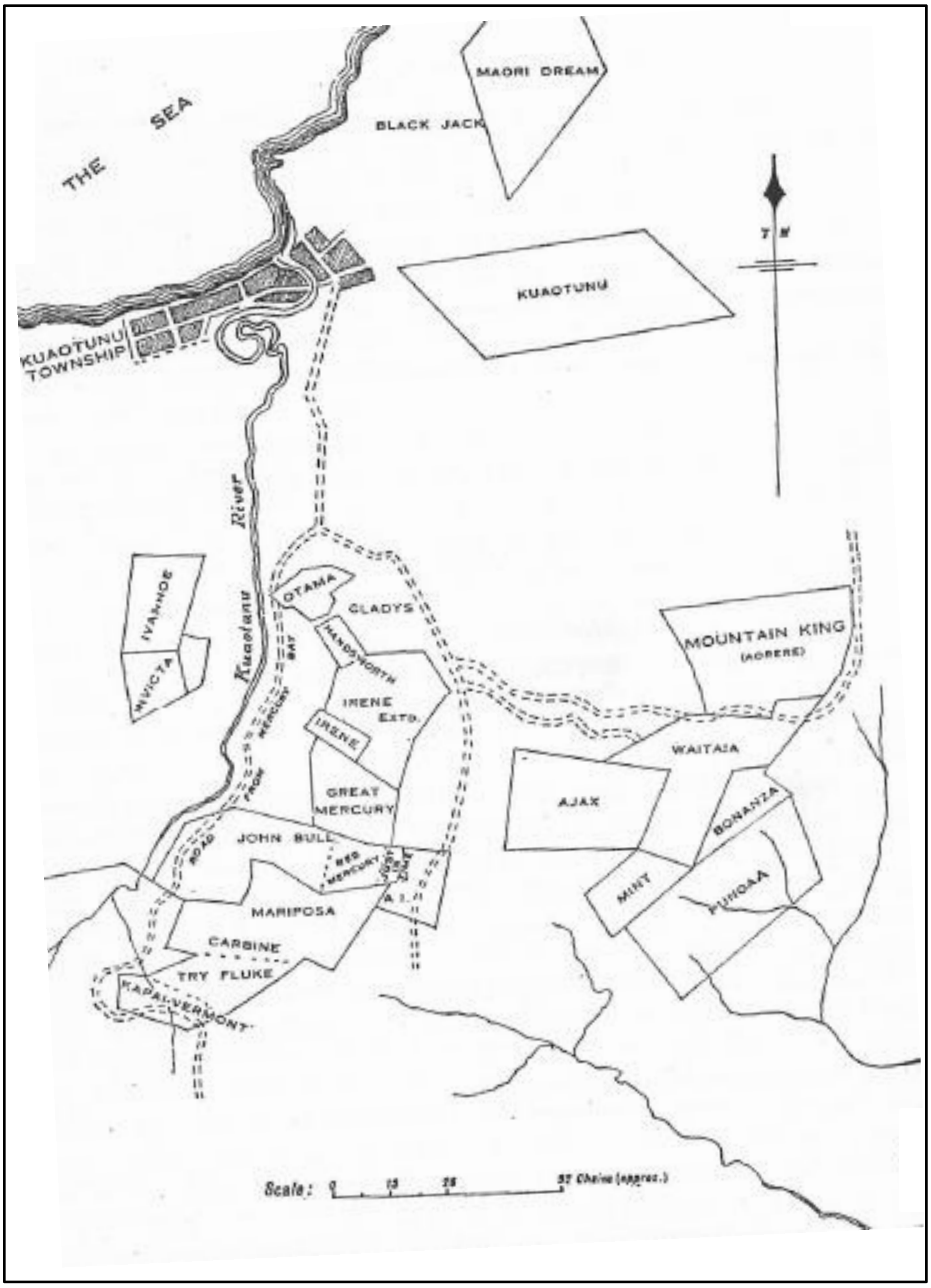


Figure 4.5: Detailed gold mining claims in the Kuaotunu area. From Downey (2002).

The Kuaotunu sites soon lost their profitability due to the inadequate extraction method of gravity settling, which caused significant amounts of gold to be flushed away and lost. Gravity settling was the process where gold contained within the bullion material would 'settle' from the extracted sediment that was being flushed through water, as gold is heavier than the sediment material. However in this case the bullion was so fine the material would not become separated from the liquid and would stay suspended in water, and thus would be flushed down the river rather than extracted. It was suggested that up to

£12,000 worth of gold was lost in the first crushing at the site (Salmon, 1963). An alternative and commonly used extraction practise was then implemented known as pan amalgamation (Craw & Chappell, 2000; Paul, 2001; Kondos *et al.* 1995). This is where mercury was added to the extracted ore along with salt (and sometimes copper sulphate) and heated to remove the silver and/or gold from the rock (Paul, 2001). At the Try Fluke Claim site they ran the tailings from the tables (i.e. where extracted rock was kept on a table-like platform) through pipes into continuous grinding followed by amalgamation pans. However, this did not prove any more successful than the previous gravity settling method. It was not until 1892 with the implementation of the cyanide process that recoveries increased along with subsequent profits. The cyanide process, also known as gold cyanidation or the MacArthur-Forrest process, is a metallurgical technique whereby gold is extracted from ore by converting the gold to a water-soluble metal complex. A metal complex consists of a central atom or ion that is metallic (i.e. gold) surrounded by bound molecules and causes the separation of the material (Kondos *et al.* 1995). This became the most prominent gold extraction method in the Coromandel region from the beginning of the 20th century (Weston, 1927; Salmon, 1963).

By the end of 1902, after a brief close down period from 1899-1901, the Try Fluke Claim, had mined 46,522 tonnes of quartz, with a yield of 30,358 oz. bullion worth £69354 (Salmon, 1963). Including the other claims in the Kuaotunu Area, at the end of the year 1933, a total of 98,362 tonnes of quartz was extracted with a yield of 94,417 oz. bullion and was worth £222,203 (Salmon, 1963). At present, there is no mining occurring in the Kuaotunu Area.

4.4.2 Paeroa

The Paeroa area, unlike Kuaotunu, did not have a mining operation within the township but rather was a focal point for multiple mining expeditions in the surrounding areas. The township came about due to mining opportunities to the north, east and south of the town. The town provided transport of the mining products out of the area via the Ohinemuri River (Ferguson *et al.* 1910; Moore & Ritchie, 1996). The majority of these mines were upstream of Paeroa but situated within the wider Ohinemuri river catchment, which flows to the west of the township. Prior to human occupation, flood waters would drain through the swampy flats surrounding the river system and take up to 3 days to make their way down to Paeroa

(Moore & Ritchie, 1996). However, deforestation and drainage of swamps across the region increased flood speeds down the Ohinemuri and sub catchments, resulting in bank collapse, aggradation of sands and silts as well as flooding to nearby settlements (Ferguson *et al*. 1910).

The major mines within the wider area of Paeroa are Maratoro, Owharoa, Karangahake, Komata, Waitekauri, Golden Cross and Waihi, with the latter the largest and still operating today (Newmont**,** 2015; see Figure 4.4). Maratoro is not discussed here as the Hikutaia River that the waste was flown into does not impact the Paeroa site in this study.

Gold was first discovered in the Owharoa Area in 1875 which led to a brief, intense gold mining rush. Unfortunately out of the larger nine claims in the area, only three proved to be of some financial success. This was due to the fact that the Owharoa claims were situated on spherolitic rhyolite or dacite-rhyolite with erratic bands of gold-rich quartz at the surface, but had little underneath. This resulted in a lack of successful claims at the sites (Downey, 2002). The Rising Sun Claim was the longest operating and most mined and profitable, with major works beginning in 1898 until 1933. Over 28,618 tonnes of quartz was mined that yielded 63,334 oz. of bullion worth £118,382 (Downey, 2002**;** Salmon, 1963).

The Karangahake area had its first gold discovery as early as 1869, but due to opposition from local Iwi tribes the land was not opened up for mining until 1875. However, mining was still not prominent in the area until 1882, due to the initially small amount of gold discovered. Similarly to the Kuaotunu area, traditional methods of mining did not justify the cost and expenditure for the returns. Wet-crushing, amalgamation and pan-amalgamation all proved to be fruitless, with as little as 45% of the bullion material being saved from the process to extract gold from (Downey, 2002). It wasn't until 1899, when the cyanide extraction process took off, did production improve. In total, over 1,125,000 tonnes of quartz was mined, yielding gold and silver that was valued at over £3,940,000 in 1935 (Downey, 2002).

The Waitekauri, Komata and Golden Cross mines were all situated within several kilometres of each other in the overlapping areas of Waitekauri and Komata. Gold was first mined from the wider area in 1875 at Waitekauri, with Komata and Golden Cross in 1892 and 1891 respectively. In 1894 the three mines were taken over by Waitekauri Gold-mining Co. with production and profits merged together. All three will be treated under the same title of Golden Cross for the purpose of this study. Gold was originally extracted using a five-stamp battery and berdan to crush the ore, with the crushed material then undergoing pan amalgamation. This site was purchased by Thomas Russell in 1894 during the take-over process by Waitekauri Gold-mining, and was replaced with a ten-stamp battery and a cyanide processing plant (Downey, 2002). This mine remained productive until the early 1910s with its closure official in 1917. From December 1991 to April 1998 the mine was re-opened as an open-pit gold and silver mine and produced 584,000 ounces of gold and 1,675,000 ounces of silver from 5 million tonnes of ore. After 1998, the mine and surrounding area began its reclamation phase, allowing vegetation to reclaim the area and the open pit to be transformed into a recreational lake, which took approximately three years (Needham, 2003).

Waihi, also known as the Martha Hill mine, was established in 1879 after gold was discovered on Martha Hill in 1878 (Waihou & Ohinemuri Rivers, 1910; Downey, 2002; Storey, 1994). Gold was extracted initially by wet-crushing the ore, followed by plate-amalgamation; however as discussed previously this did not produce favourable results for the ore that had a refractory nature whereby the gold contained within the bullion material would end up being flushed down the river rather than extracted. Similarly to the Golden Cross mine, the extraction process then shifted to using mercury amalgamation techniques whereby the ore was crushed dry before chemicals were added and it was panned. Though this improved production results, it wasn't until the mine was purchased in 1894 by the Waihi Gold Mining Company and cyanidation began that the mines reached the desired profits (Storey, 1994). Waihi operated in this manner from 1894 until its closure in 1952. In this time it had produced 5.6 million ounces of gold and 38.4 million ounces of silver from 11,935,000 tonnes of ore. On 15th June 1988 the Martha mine officially reopened and continues to operate today along with the Favona and Trio mines which were opened and operational in 2006 and 2011 respectively. Approximately 400 people work at the Waihi, Favona and Trio mines at present, producing around 100,000 ounces of gold and 750,000 ounces of silver annually (Newmont, 2015).

Chapter 5: Methodology

This thesis used trace element analysis in conjunction with PSA to determine the sediment characteristics, and therefore evidence of disturbance, were two-fold. Firstly to use techniques that are relatively underutilized in New Zealand and secondly due to the reliability of these techniques to achieve the desired outcome of this study (Jansen *et al*. 1998; Croudace, 2006; Rothwell & Rack, 2006; Ene *et al*. 2009) as they have been shown to be useful proxies in other international studies (e.g. Macklin *et al*. 1994; Hudson-Edwards *et al*. 1997; Manju *et al*. 2014; Velasquez-Lopez *et al*. 2010).

5.1 Core collection

To assess the impacts of mining operations reviewed in Chapter 4 on the Kuaotunu and Ohinemuri floodplains, cores were extracted using a motorised percussion corer and a vibracorer. In total, six cores were extracted from the Kuaotunu and Ohinemuri floodplains. The locations of the six cores are shown in Figure 5.1 with photographs of each cores displayed in Images 5.1-5.9. The associated coordinates are presented in Table 5.1. The lengths of the cores varied from 2 m up to 5 m. The percussion corer was used to recover three cores from the Ohinemuri River floodplain and the Kuaotunu Stream floodplain in 1 metre sections. The vibracorer was used to extract three cores of sediment from within the Kuaotunu Stream. The decision to use two different types of corers was influenced by the setting the sediment was extracted from. The motorised percussion corer allowed for easier penetration and extraction of floodplain material while the vibracorer obtained the entirety of the in-stream sediment cohesively and within one steel core. Both coring methods have their advantages and disadvantages (Glew *et al*. 2001). Percussion corers are ideal for dense mineral-rich sediments as they can penetrate successfully into the surfaces of bogs, floodplains and terraces more so than other core types due to the motorised 'hammer' driving weight which drives the core tube into the sediment (Gilbert & Glew, 1985**;** Reasoner, 1986**,** Nesje, 1992). Vibracorers offer the ability of acquiring unconsolidated sediments that are difficult to extract with percussion corers, such as sand, as well as extracting a continuous sediment sequence (Glew *et al*. 2001). Furthermore vibracorers are ideal for sandy silt and muddy sand material (Burge & Smith, 1999; Esker *et al*. 1996; Imperto, 1987**;** Glew *et al*. 2001), which is dominant around the Kuaotunu coring sites.

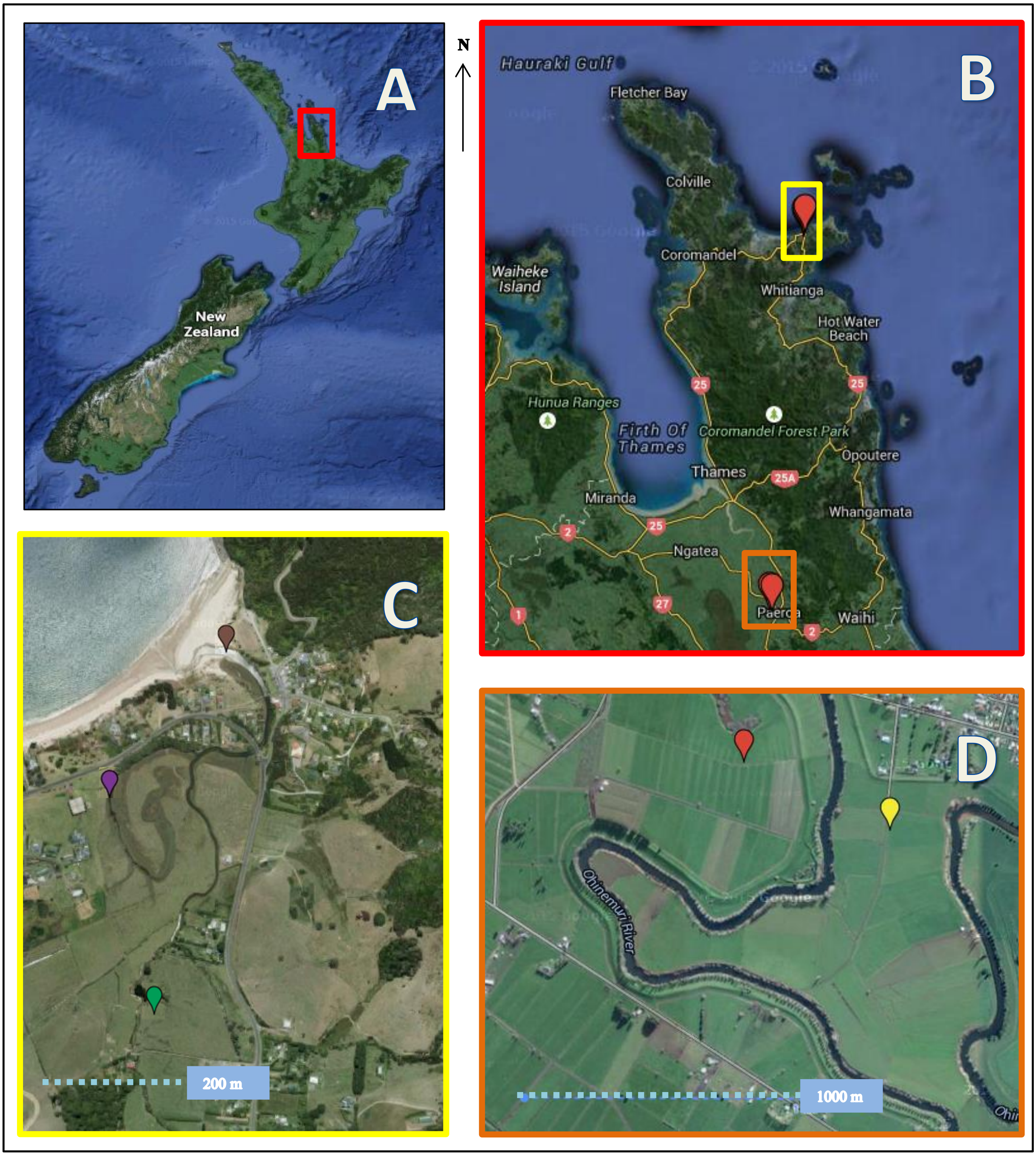


Figure 5.1: Location of cores extracted from the Coromandel. A: New Zealand with Coromandel area in red box. B: Coromandel area with yellow box the Kuaotunu area and the orange box the Paeroa area. C: Cores extracted from Kuaotunu (Green = Kuaotunu Floodplain, Purple = K3 & K4, Brown = K5 cores). D: Cores extracted from outside of the Paeroa township (red = Gerard Road, yellow = Maori Road core).

Image 5.1 (above): Location of Gerard Road Core.

Image 5.2 (below): Percussion corer used to extract the 4 m of core from the Gerard Road site.

Image 5.3 (above): Location of Maori Road Core looking towards the stopbanks of the Ohinemuri River.

Image 5.4 (below): Percussion corer extracting 2 m of core from the Maori Road site.

Image 5.5 (above): Location of Kuaotunu Floodplain core, looking out to sea and Kuaotunu River.
Image 5.6 (below): Percussion corer extracting core sections from the Kuaotunu floodplain.

Image 5.7 (above): Kuaotunu River, location of Kuaotunu 3 and Kuaotunu 4 cores locations

Image 5.8 (below): Location of Kuaotunu 3 core extraction with vibracorer.

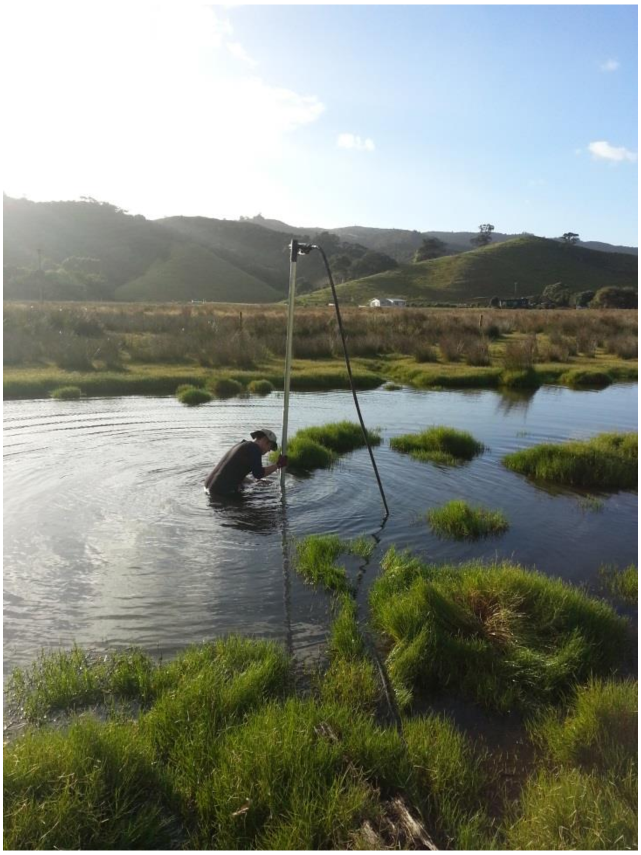


Image 5.9: Location of Kuaotunu 4 core. To the right where Dr. Fuller is standing in this photograph is the location of the Kuaotunu 3 core.

Core Name	Coordinates
Gerard Road	37°22.685 175°39.121
Maori Road	37°22.759 175°39.524
Kuaotunu Floodplain	36°43.730 175°43.582
Kuaotunu 3	36°43.434 175°43.537
Kuaotunu 4	36°43.434 175°43.537
Kuaotunu 5	36°43.258 175°43.741

Table 5.1: Coordinates of the locations of the 6 cores. Kuaotunu cores 3 & 4 were located less than 2 metres apart therefore no distinct difference in location.

Once the cores were extracted they were sealed in the field and transported back to Massey University, where they were split in two, with one half shipped to Aberystwyth University.

5.2 Geochemical Analysis

At Aberystwyth the cores underwent geochemical analysis using an ITRAX core scanner and NITON Handheld XRF. Unfortunately due to technical problems with the ITRAX only two out of the six cores were analysed before a malfunction, which was not repaired in the time frame of this project. Thus the geochemical results have become supplementary data for the purpose of this study and can be found in the Appendices 5.1 & 5.2. The remaining half of each core was logged and sampled for Particle Size Analysis.

NITON XRF analysis was carried out on five cores to investigate geochemical variations. The handheld NITON unit is designed for quick accurate, and reliable elemental analysis, which is done by scanning the area of interest without damaging the sample (Ene *et al*. 2009; Zolitschka *et al*. 2001). It works by determining the chemistry of a sample by measuring the spectrum of the x-rays emitted by the different elements present in the sample when it is illuminated by x-rays. Similarly, the ITRAX scanner also determines the geochemistry of sediments, as well as physical characteristics. It provides a high quality optical image, x-ray spectral results, and an analytical summary of the composition of elements within the core (Croudace *et al*. 2006). It analyses the sample by focusing an intense micro-X-ray beam through a flat capillary waveguide to irradiate the samples; this enables x-radiography and x-ray fluorescence analysis to determine the elements present, and outputs the data as semi-quantitative counts (Croudace *et al*. 2006). ITRAX analysis was conducted on two of the six cores; Maori Road and the Gerard core. The geochemistry data from the NITON XRF (and ITRAX, where obtained) was graphed alongside the stratigraphy and particle-size analysis for each core. These analyses were undertaken to determine if landscape disturbances in the catchment had left any distinctive geochemical signals, based on the relation of where the changes occurred in the record and when humans began mining in the area. The chemicals of interest were Strontium, Rubidium, Lead, Zinc, Arsenic, Iron and Manganese.

5.3 Stratigraphy and particle size analysis

The sediments in the cores were logged and described according to the component-based sediment classification by Troels-Smith (1955), with any organic material noted. The raw data for this is displayed in Appendices 5.3-5.8. Areas of interest, such as distinctive boundaries and transitions, and visual and textual changes, were photographed. These results were entered into SedLog software to create a stratigraphic record of each core. Cores were sampled at 10 cm intervals for the particle-size analysis. Each sample comprised 4 grams of sediment. Additional samples were taken from zones of interest which were not captured in the 10cm sampling intervals..

Particle -Size Analysis (PSA) is the measurement of the size distribution of discrete particles in a sediment sample (Gee, 2002). Using chemical, mechanical or ultrasonic means to destruct or disperse soil aggregates and separate the particles based on size gives precise information on the physical makeup of samples. This helps to describe soils and the environment they come from along with a history of events that occurred. This method has been used in many studies looking at human disturbance of the environment (e.g. Elliot *et al*. 1995; Goff, 1995; Glade, 2003; Richardson *et al.* 2014). Previous work has shown that rapid changes in grain size can be related to flood events, changes in sediment supply in the local or regional catchment, or natural disasters (e.g. landslides) (Glade, 2003; Richardson *et al.*2013; Page & Trustram, 1997). Therefore PSA was carried out alongside the geochemical analyses to further investigate the timing and impact of disturbance in the study area.

In total 167 samples for PSA were collected from the six cores. Of these samples, 132 were used for particle size analysis. Samples collected from the K5 core were not analyzed due to the lack of textural and physical colour changes observed when the core was described.

Approximately 30 ml of hydrogen peroxide (25%) was added to each sample in a 450 ml beaker, and then placed in a fume cupboard and left to react. Hydrogen peroxide was added to the samples to remove any organic matter present in the sample. Once the chemical reaction ceased (which took up to 2 weeks for organic-rich samples), samples were centrifuged at 5000 rpm for 5 minutes in 25 ml test tubes. Each sample was then decanted, washed with distilled water, and centrifuged again, with the process repeated until all the hydrogen peroxide was removed. Some samples displayed signs of flocculation, whereby fine particles clump together into a floc which may float to the top or settle at the bottom of the sample (Eisma, 1986; Halverson & Panzer, 1980). Flocculation can be a problem when analyzing sediment samples as it may give a misrepresentation of the particle sizes within a sample (Eisma, 1986). Each sample was agitated before analysis to prevent flocculation. A Horiba Partica LA-950v2 laser scattering particle size distribution analyzer was used for the PSA. This system operates by detecting the correlation between the intensity and the angle of light scattered from a particle and then calculating the size based on the Mie-scattering theory (HORIBA, 2015; Wriedt, 2012). Each sample was analyzed three times, with the mean of the analyses plotted alongside the geochemical and staritgraphic descriptions.

5.4 Radiocarbon dating and sedimentation rates

During the stratigraphical analysis, pieces of wood were found in the Maori Road and Gerard Road cores at 1.6 m and 1.0 m depth, respectively. These were sent away for radiocarbon dating to the Waikato Radiation Laboratory. Radiocarbon dates allow the establishment of a chronology for these two cores, which gives insight into the timing of changes in the environment, and allows estimation of sedimentation rates. Radiocarbon dating measures the amount of ^{14}C decay in an organic sample (e.g. animal or plant) to determine the age of death. From this, the age of adjacent or related deposits can be determined (Last & Smol, 2001). Once the radiocarbon age was determined, estimated sedimentation rates were calculated for the Gerard Road and Maori Road cores for the time period between the data and the present. Geochemical signals of anthropogenic (European) disturbance were also used as chronohorzions. Where there was a peak in trace elements that are associated with mining that were analysed for this study (e.g. Arsenic, Lead) , the sedimentation rate stopped and a new one was calculated from that point to the top of the core. This is because human history records gave an approximate year of when mining started in the areas and therefore allowed the calculation of the sedimentation rate since then to the present day. For cores that did not have material suitable for radiocarbon dating if there was evidence of mining, and therefore human interference with the natural processes, this was deemed the end point of the natural sedimentation rate. The new sedimentation rate was then calculated as above from the mining layer to the top of the core to give an approximate sedimentation rate before and after human arrival.

Chapter 6: Results

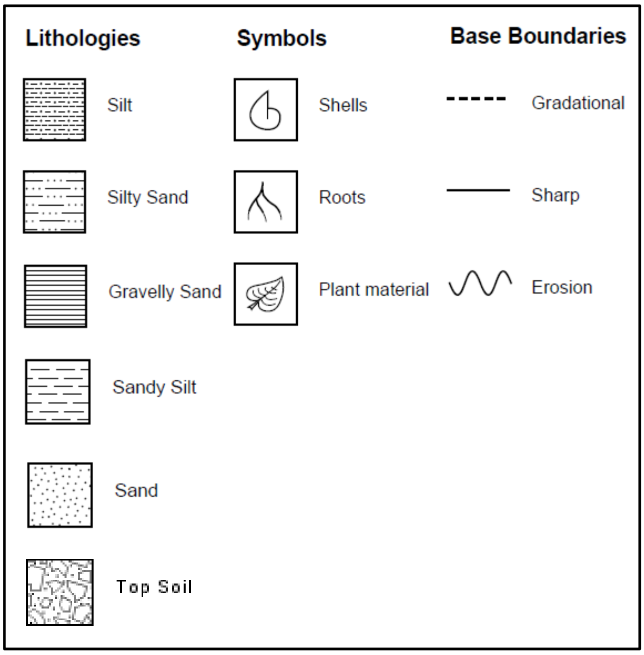
6.1 Stratigraphy:

Graphical illustrations of the six cores extracted from the Paeroa floodplain, the Kuaotunu Stream and Kuaotunu floodplain are presented in Figures 6.1-6.6. The written descriptions of those cores are compiled in appendices 5.3-5.8.

6.1.1 Maori Road Core:

From the base of the core (3 m) to 0.6 m the texture of the sediment was a plastic-like, smooth dark clay with sand particles decreasing to 0.6 m. The colour of the sediment also darkened towards 0.76 m, from a 2.5Y 5/3 at the base to 10YR 3/2. The core showed clear evidence of organic material being present throughout the core by the large amounts of orange flecks indicating oxidation of organic material. There was a collapse within the core between core segments M2 and M3 from 2.06 m to 2 m as well as at 1.53 to 1.50 metres. A piece of wood was found at 1.6 m that was sent away for radio carbon dating. From 0.6 m to 0.52 m there was a clear band of yellow-brown-orange 10YR 5/6 material that had large sand and silt particles. From 0.52 m to 0 m the sediment was fine-grained with a silty sand texture.

Key for Sedimentology diagrams created from SedLog program for Figures 6.1-6.6.



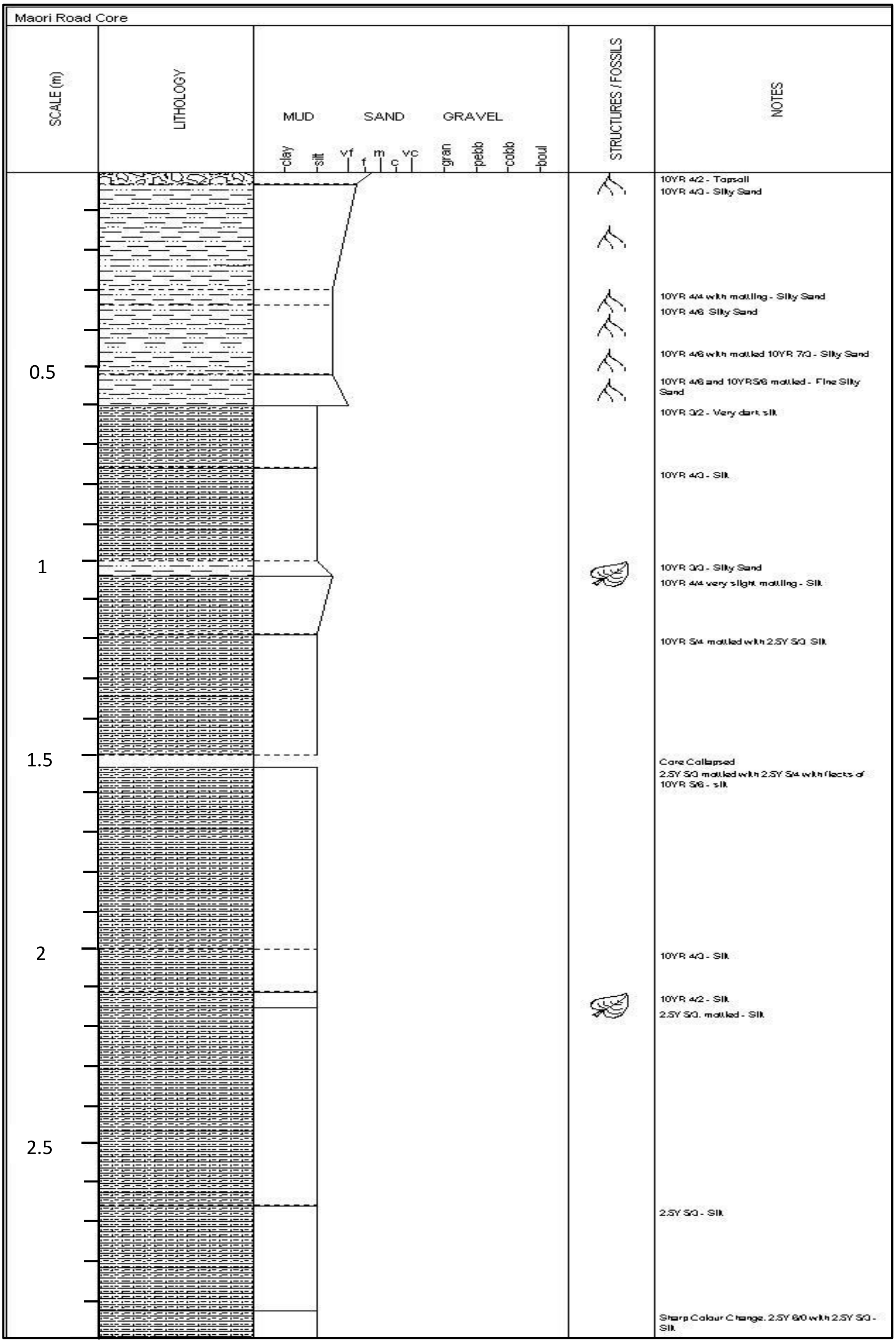


Figure 6.1: Maori Road core lithology

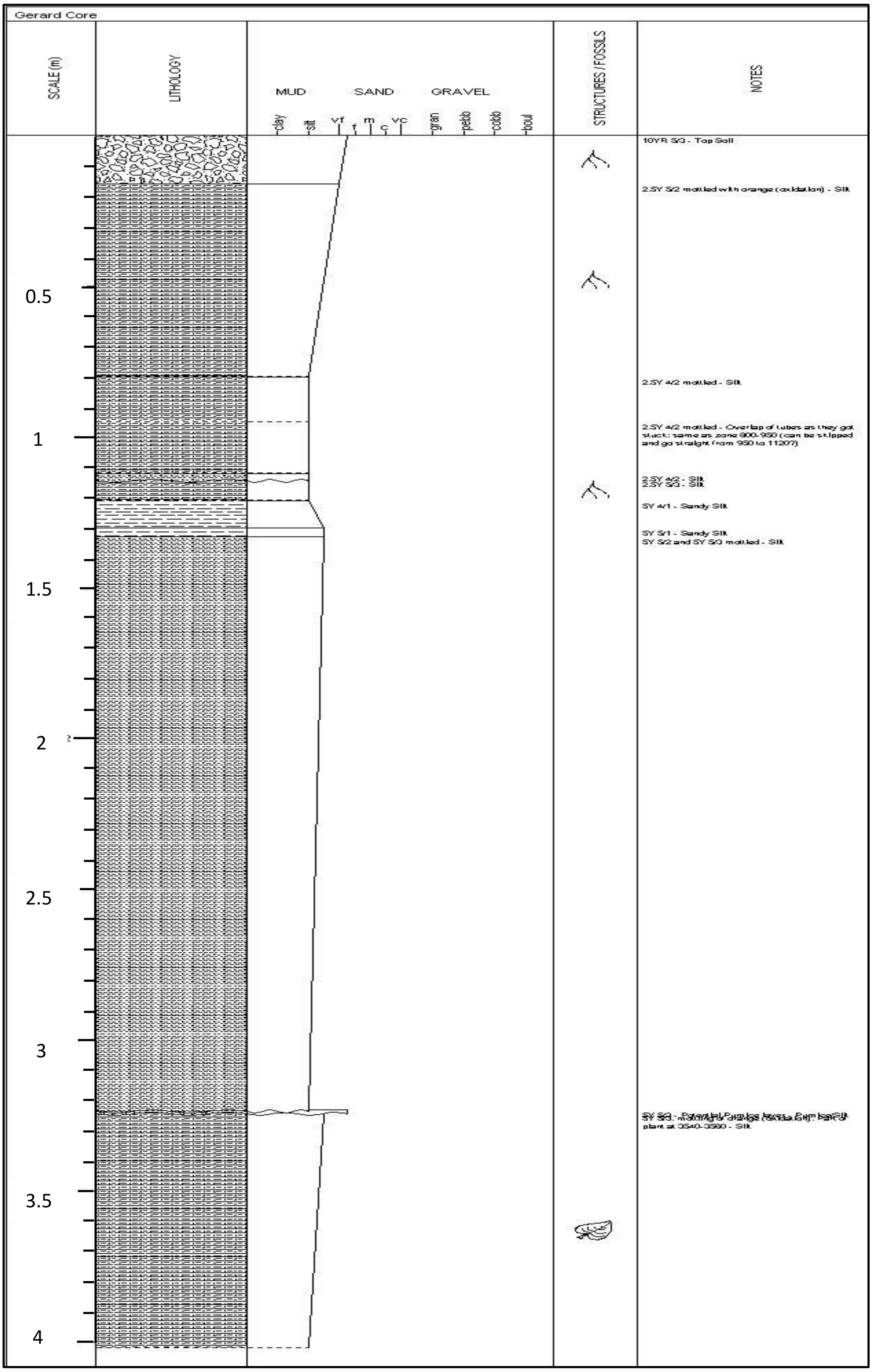


Figure 6.2: Gerard Road core lithology

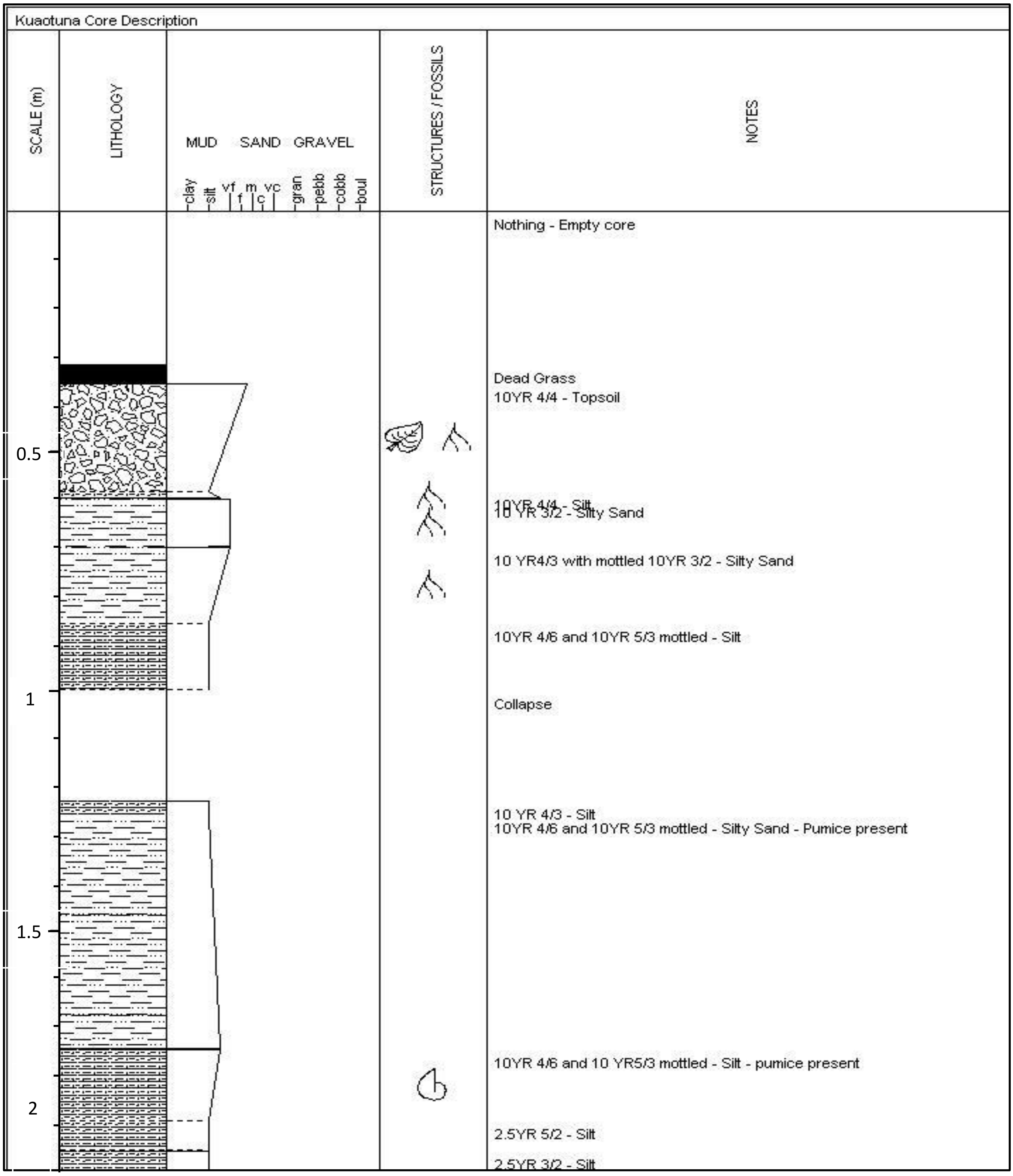


Figure 6.3: Kuaotunu Floodplain core lithology

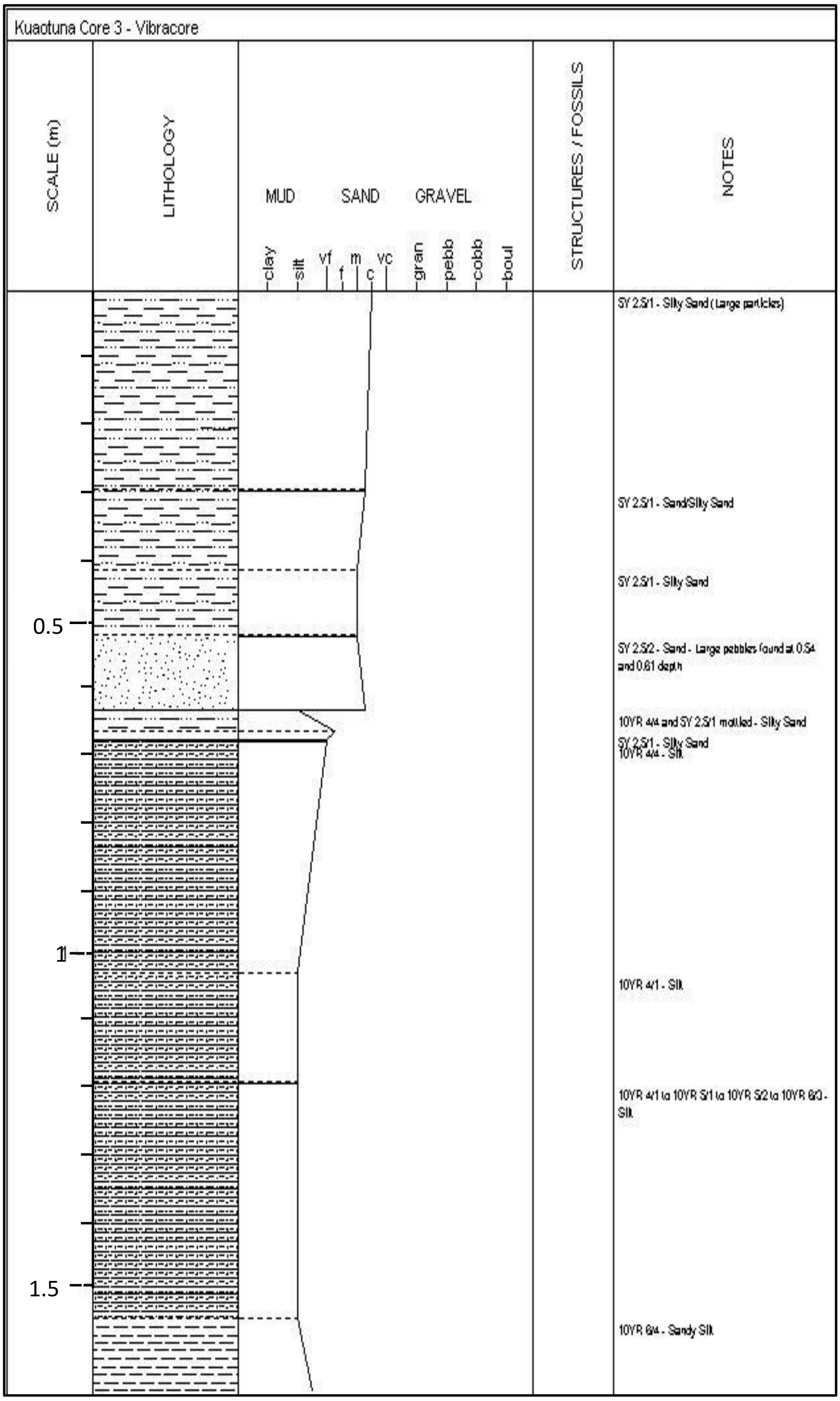


Figure 6.4: Kuaotunu 3 core lithology

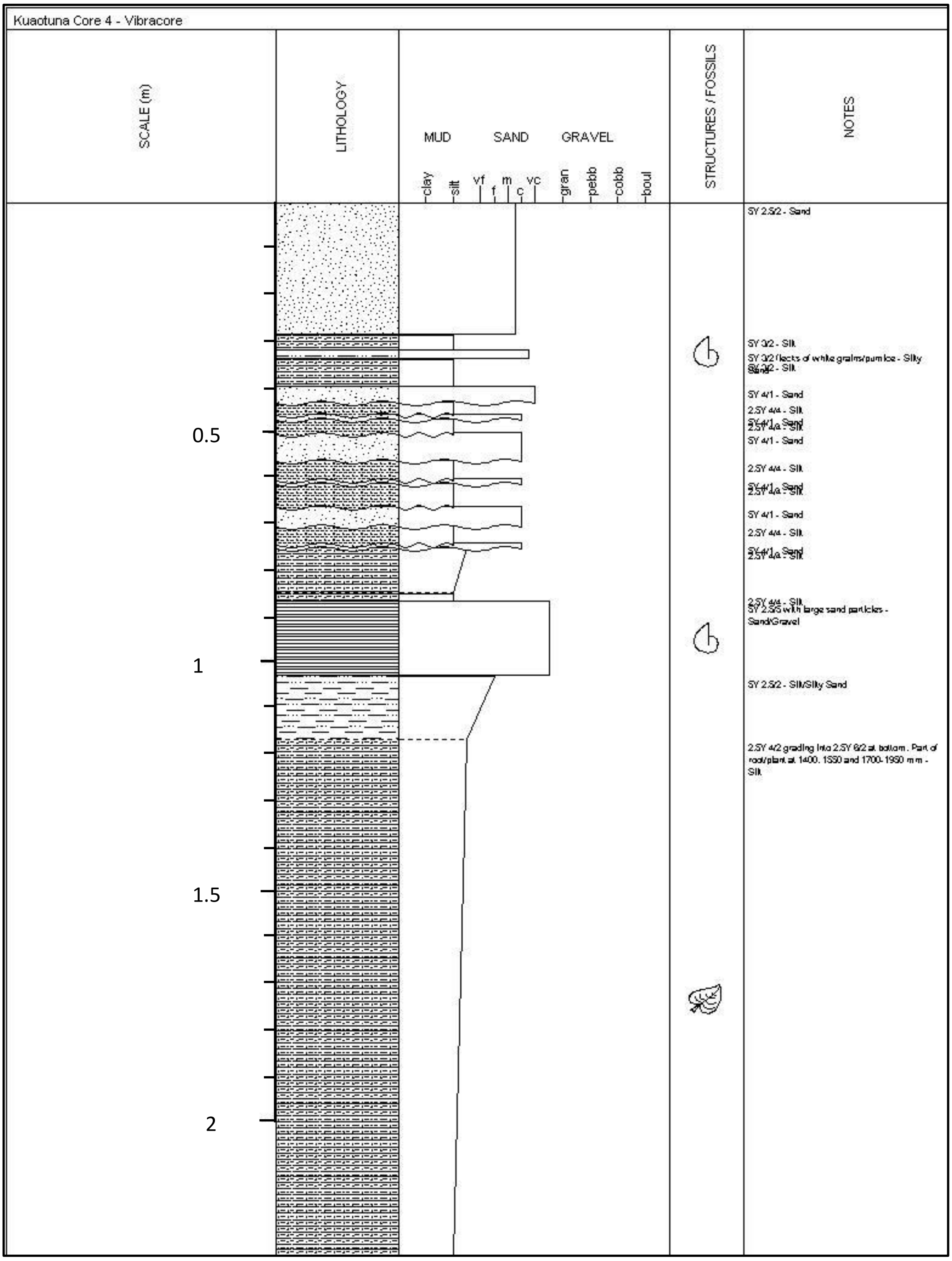


Figure 6.5: Kuaotunu 4 core lithology

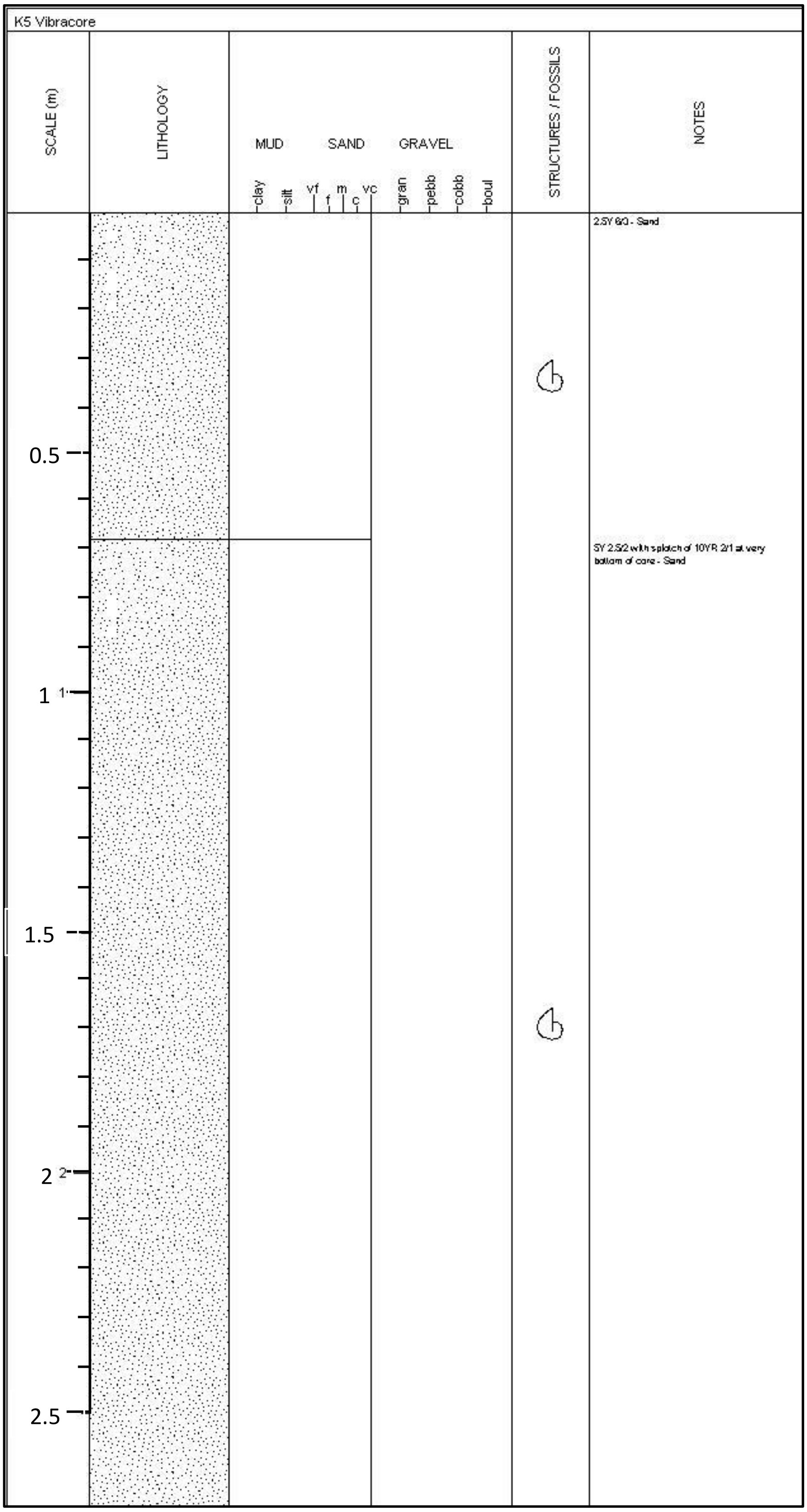


Figure 6.6: Kuaotunu 5 core lithology.

6.1.2 Gerard Road Core:

From the base of the core (4 m) to 3.1 m, there is a significant decrease in oxidation of organics that were present in the core. A section of plant was found at 3.56 to 3.5a m which was not radiocarbon dated as it appeared to be contamination during extraction of the core. From 3.1 m to 1.33 m silt and clay remain dominant, grading in colour from 5Y 5/3 to 5Y 5/1. At 1.3 m there is a distinct transition boundary into a compacted, fine-silty sand layer or reworked volcanic material. This grades upwards from 1.3 m to 1.21 m, decreasing from large sandy grains into smaller, silty particles. From 1.21 m to 0.162 m the sediment is relatively uniform with clay dominating and some fine roots present. From 1.120 m to 1.0 m the tubes used for extracting the cores became jammed resulting in an overlap of tubes and contamination of the core material; this was excluded and assumed the true representation of the stratigraphy of the floodplain continues from 1.120 m to 1.0 m uninterrupted. A piece of plant material was extracted from 1.0 m for radiocarbon dating

6.1.3 Kuaotunu Floodplain Core:

From 1.9 m to 1.748 m there is a distinct change in texture to a decrease in larger, gritty pumice particles and a increase in clay. The colour grades from a 2.5YR 5/2, 3/2 mottling at the base to 10YR 5/3 at 1.9 m to 10YR 4/6 mottling at 1.26 m. From 1.26 m to 1 m the core appears to have collapsed on itself and has been excluded with the core assumed to continue from 1.26 m to 1 m uninterrupted. A distinct band of dark brown, 10YR 3/2 silty clay transitions from 0.86 m to 0.6 m, with Fine roots and small amounts of plant material throughout this section. From 0.6 m to the top of the core there is a sandy horizon that transitions into the top soil of the Kuaotunu floodplain.

6.1.4 Kuaotunu 3 Core:

From the base of the core (1.66 m) the colour grades from 10 YR 6/4 to 10YR 4/4 by 0.68 m, where clay and silt dominate, to increasing amounts of sand. At 0.68 m to 0.63 m there is a distinct boundary where sandy particles increase, with a colour change at 0.63 m to 5Y 2.5/2. From 0.63 m the colour grades to 5Y 2.5/1 with increasing sand and silt particles, with little clay present. Large stone were found from 0.63 m to 0 m that were well-rounded, with no organics present.

6.1.5 Kuaotunu 4 Core:

From 2.3 m to 1.03 m the amount of sand and silt increased with a decrease in clay grading in colour from 2.5Y 6/2 to 5Y 2.5/2. No organics were present except for parts of fine roots found at 1.95 m -1.7 m, 1.55m and 1.4 m. This core was characterised by semi-distinct bands of sand between silty layers from 1.03 m to 0.4 m. From 1.03 m to 0.87 m fine gravels were present along with large sand particles. A very distinct band of large coarse sandy particles with shells, which were identified as *Austrovenus stutchburyi* of the Veneridae family (Ahyong, 2011), were present at 0.87 m.

6.1.6 Kuaotunu 5 Core:

A piece of wood was found at 2.55 m depth but otherwise no organics were present. Except for a distinct colour transition at 0.68 from 2.5 Y 2.5/2 to 2.5Y 6/3 the core was uniform coarse sand with no evidence of clay or silt. *Austrovenus stutchburyi*, bivalve shells, were present throughout this core along with large, well-rounded pebbles.

6.2 PSA Results:

During the sample preparation it was noted which samples showed significant reaction to the hydrogen peroxide (this indicated high organic matter content) as well as which samples had evidence of flocculation; these are summarized in Tables 6.1-6.5.

For each sediment sample, three runs were performed giving three results per sample. These results were then averaged with mean values used to represent each sample. The particle size analyser returned results in micrometres, but for simplicity the results aggregated into sand (2mm - 63 µm, silt (63 µm - 2 µm) and clay (<2 µm) size ranges (see Appendices 6.1-6.5). As only one core showed evidence of very fine gravel it was decided no separate category for larger particles would be differentiated. For each sample the percentage of clay, silt and/or sand was graphed, as shown in Figures 6.7-6.12 along with the geochemical results, which are discussed below in more detail.

Sample (depth in cm)	Reaction to Hydrogen Peroxide	Degree of Floculation
M1 0	low	nil
M1 10	low	nil
M1 20	medium	nil
M1 30	medium	nil
M1 40	medium	nil

M1 50	medium	nil
M1 59	medium	nil
M1 61	high	nil
M1 70	high	nil
M1 80	high	nil
M1 90	high	nil
M1 100	medium	nil
M2 102	medium	nil
M2 110	medium	medium
M2 120	medium	medium
M2 130	medium	medium
M2 140	medium	medium
M2 150	medium	medium
M2 160	medium	medium
M2 170	low	nil
M2 180	low	nil
M2 190	low	nil
M2 200	low	nil
M3 205	low	nil
M3 215	low	nil
M3 220	low	nil
M3 230	low	medium
M3 240	low	medium
M3 250	low	nil
M3 260	low	nil
M3 270	low	nil
M3 280	low	nil
M3 290	low	nil
M3 299	low	nil

Table 6.1: Maori Road Core amount of reaction indication organic matter and flocculating of the samples on a nil to high scale.

Sample (depth in cm)	**Amount of Reaction**	**Flocculating Amount**
K1 40	medium	nil
K1 50	low	nil
K1 60	low	nil
K1 62	low	nil
K1 71	low	nil
K1 80	low	medium
K1 84	low	medium
K1 90	high	nil
K1 100	high	high

K2 126	low	nil
K2 130	low	medium
K2 140	low	medium
K2 150	medium	medium
K2 160	low	medium
K2 170	low	medium
K2 180	low	medium
K2 190	low	medium
K2 200	low	medium

Table 6.2: Kuaotunu Floodplain core amount of reaction indication organic matter and flocculating of the samples on a nil to high scale.

Sample (depth in cm)	Amount of Reaction	Flocculating Amount
K3 10	low	low
K3 20	low	low
K3 30	low	low
K3 40	low	nil
K3 50	low	nil
K3 60	low	nil
K3 66	low	nil
K3 70	low	nil
K3 80	low	nil
K3 90	low	nil
K3 100	low	nil
K3 110	low	nil
K3 120	low	nil
K3 130	low	nil
K3 140	low	nil
K3 150	low	nil
K3 160	low	nil

Table 6.3: Kuaotunu 3 core amount of reaction indication organic matter and flocculating of the samples on a nil to high scale.

Sample (depth in cm)	Amount of Reaction	Flocculating Amount
K4 10	low	nil
K4 20	medium	medium
K4 30	low	medium
K4 40	low	medium
K4 43	medium	nil
K4 46	high	medium
K4 60	high	medium

K4 70	high	low
K4 80	low	low
K4 90	low	nil
K4 95	low	nil
K4 100	low	nil
K4 110	high	low
K4 120	high	low
K4 130	high	low
K4 140	high	low
K4 150	high	nil
K4 160	high	nil
K4 170	low	nil
K4 180	low	nil
K4 190	low	nil
K4 200	low	nil

Table 6.4: Kuaotunu 4 core amount of reaction indication organic matter and flocculating of the samples on a nil to high scale.

Sample (depth in cm)	**Amount of Reaction**	**Flocculating Amount**
G1 16	low	nil
G1 20	low	nil
G1 30	low	nil
G1 40	low	nil
G1 50	low	nil
G1 60	low	nil
G1 70	low	nil
G1 80	low	medium
G1 90	high	medium
G2 110	low	nil
G2 120	low	nil
G2 130	high	nil
G2 133	high	nil
G2 140	high	nil
G2 150	high	nil
G2 160	high	medium
G2 170	high	medium
G2 180	medium	medium
G2 190	low	medium
G2 200	low	medium
G3 210	low	medium
G3 220	low	medium
G3 230	low	medium

G3 240	low	medium
G3 250	high	medium
G3 260	high	medium
G3 270	low	medium
G3 280	low	medium
G3 290	low	medium
G3 295	low	medium
G4 300	low	medium
G4 310	low	medium
G4 320	low	medium
G4 330	low	medium
G4 340	low	medium
G4 350	low	medium
G4 360	low	medium
G4 370	low	medium
G4 380	low	medium
G4 390	low	medium
G4 400	low	medium

Table 6.5: Gerard Road core amount of reaction indication organic matter and flocculating of the samples on a nil to high scale.

Due to the uniformity of the K5 core no PSA was conducted on the core as it was evident from the visual core stratigraphy that the vast majority of the core was predominantly sand particles greater than 63 µm in size.

6.2.1 Maori Road Core:

From 0 to 0.51 m sand dominates the core with greater than 60% of the total sediment material size greater than 63 micrometers. This changed at 0.61 meters where sand decreased and silt increased. At 0.7 m in depth, clay particles increased with a further decline in sand particles. Silt remained the major grain size (> 80%) from 0.61 m with sand increasing at depths 1.0 m (45.5%) and 2.15 m (49.6%) with clay remaining as a minor fraction from 1.6 m down throughout the core.

6.2.2 Gerard Core:

Silt made up the majority of the core with greater than 80% of the grain size with the exceptions at 1.3 and 1.33 m in depth where a large increase of sand was noted (78% and 34% respectively). Clay was also present throughout in a minor percentage (12 – 5%) with the exception at 1.3 to 1.40 which coincided with the significant increase in sand particles and subsequent decrease in silt.

6.2.3 Kuaotunu Floodplain Core:

Silt composed the majority of each sample with the exceptions of 1.0 m, 1.3 m and 1.5 m where sand was predominant. Clay was present in every sample ranging from 1% at 1.7m to 10.6% at 0.5 m with a slight trend of decreasing throughout the core.

6.2.4 Kuaotunu 3 Core:

The distribution of grain sizes throughout this core fluctuated significantly, with no clay sized particles detected until 0.66 m to 1.0 m. Overall silt dominated with the greatest percentage of 86% at 1.0 m though sand was dominant at 0.4 m (83.8%) and 0.60 m (81.9%) specifically, with the two factions more or less the equal from 1.2 m onwards.

6.2.5 Kuaotunu 4 Core:

Transitions between silt and sand particles dominating the samples fluctuated throughout this core, with an overall trend of sand dominating at 0.1 m, 0.43-0.46 m, 0.90-1.10 m and 1.50-2.00 m with silt the latter depths. Clay was only present from 0.46 to 0.70 m with the greatest amount at 0.60 m (1.63% of the sample).

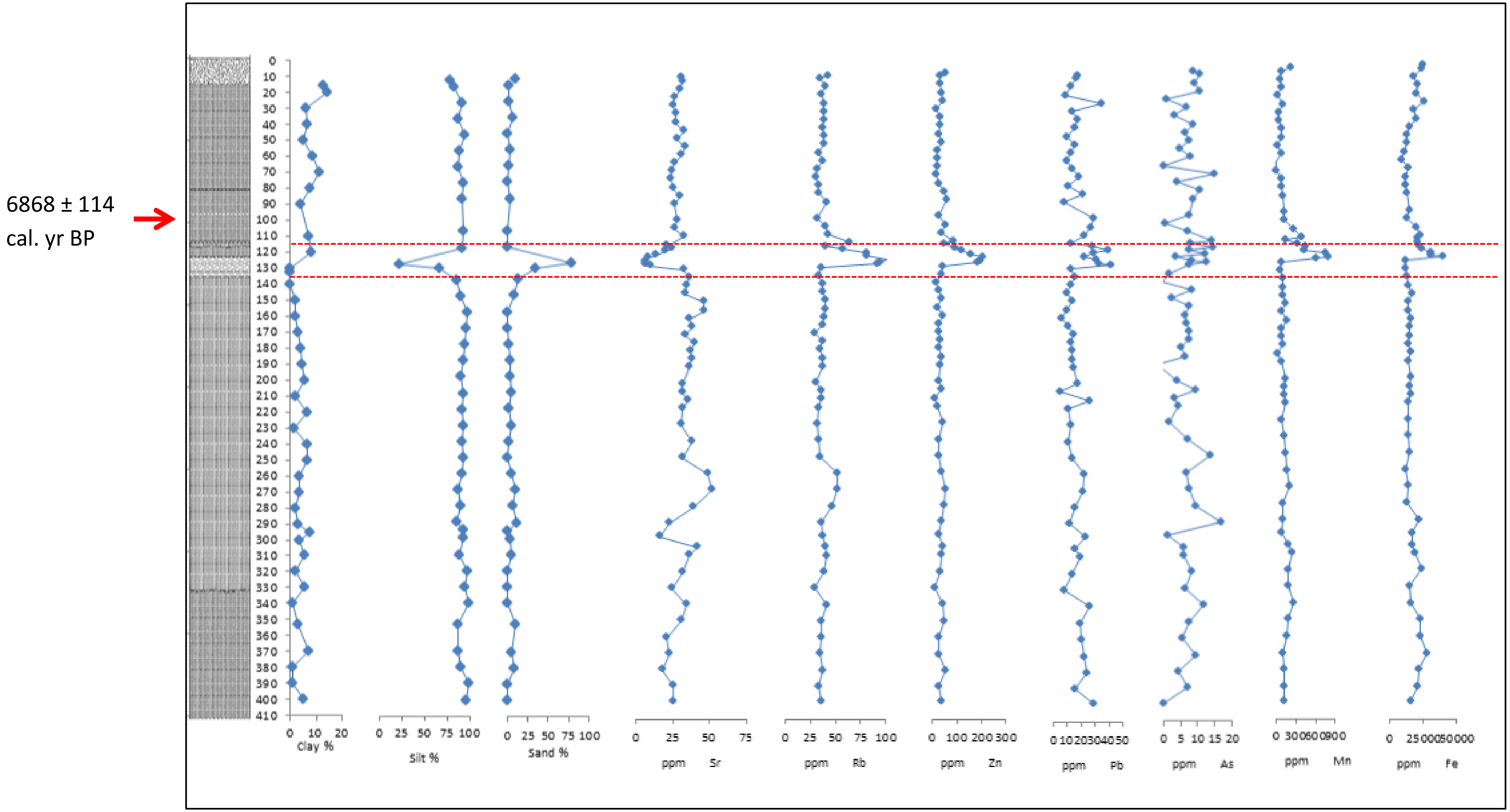


Figure 6.7: Gerard Road Core stratigraphy, PSA and geochemistry results. Red dashed lines show band of tephra identified in the core.

4001 ± 28 cal. yr BP

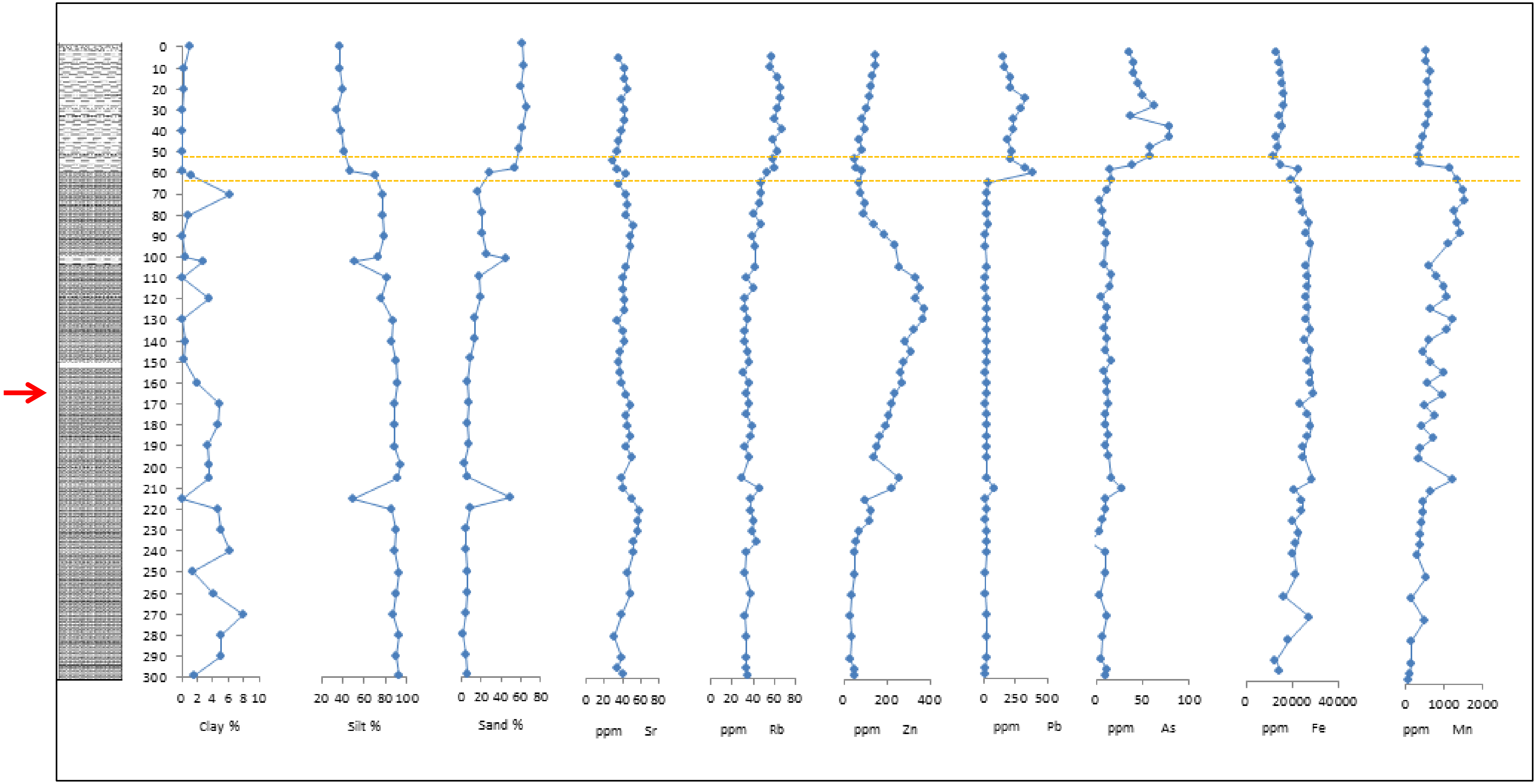


Figure 6.8: Maori Road core stratigraphy, PSA and geochemistry results. Orange dashed lines illustrate sharp transition into the ‘mining’ layer, which grades to the top of the core.

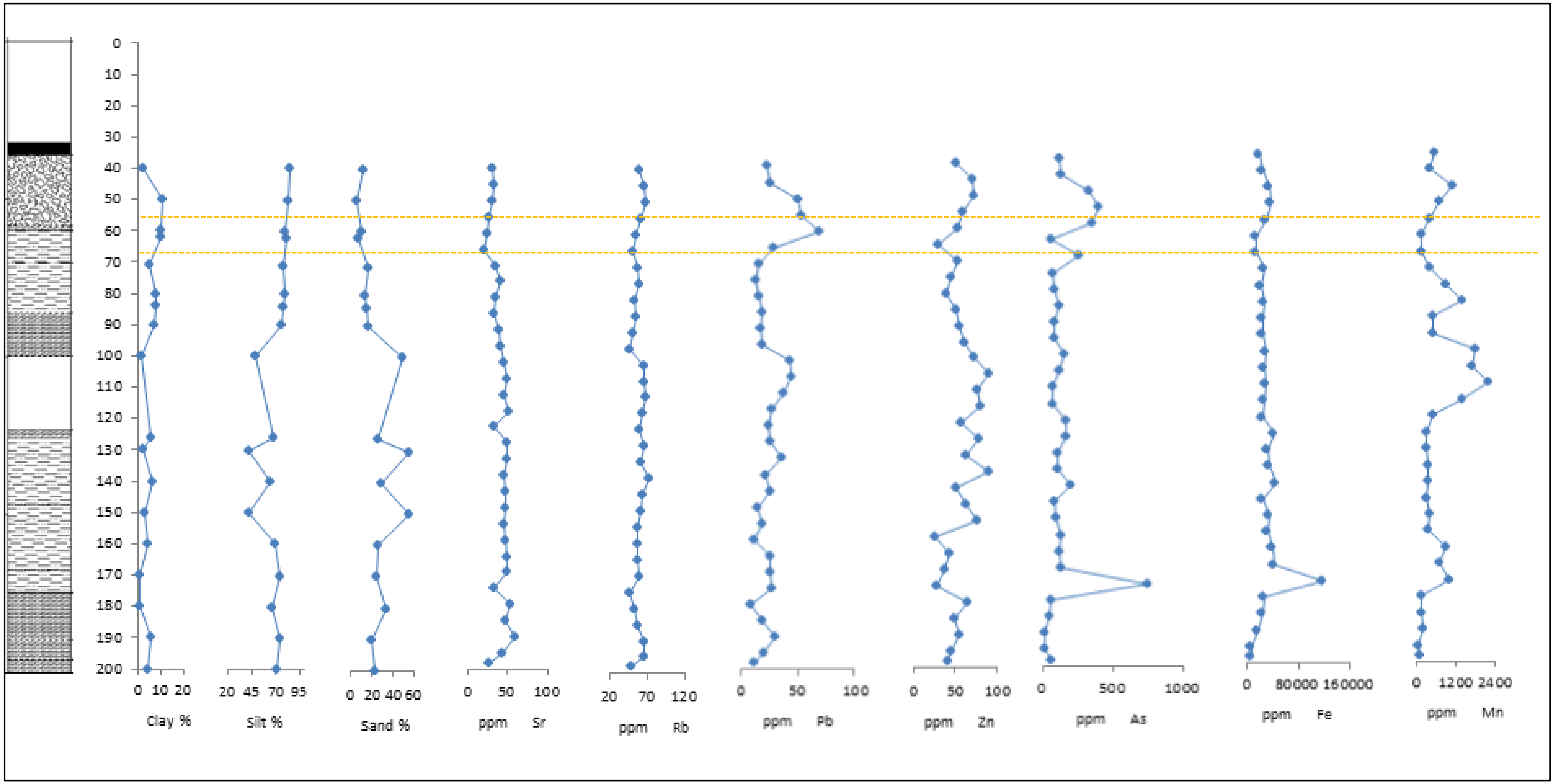


Figure 6.9: Kuaotunu Floodplain core stratigraphy, PSA and geochemistry results. Orange lines where a potential ‘mining’ layer could be.

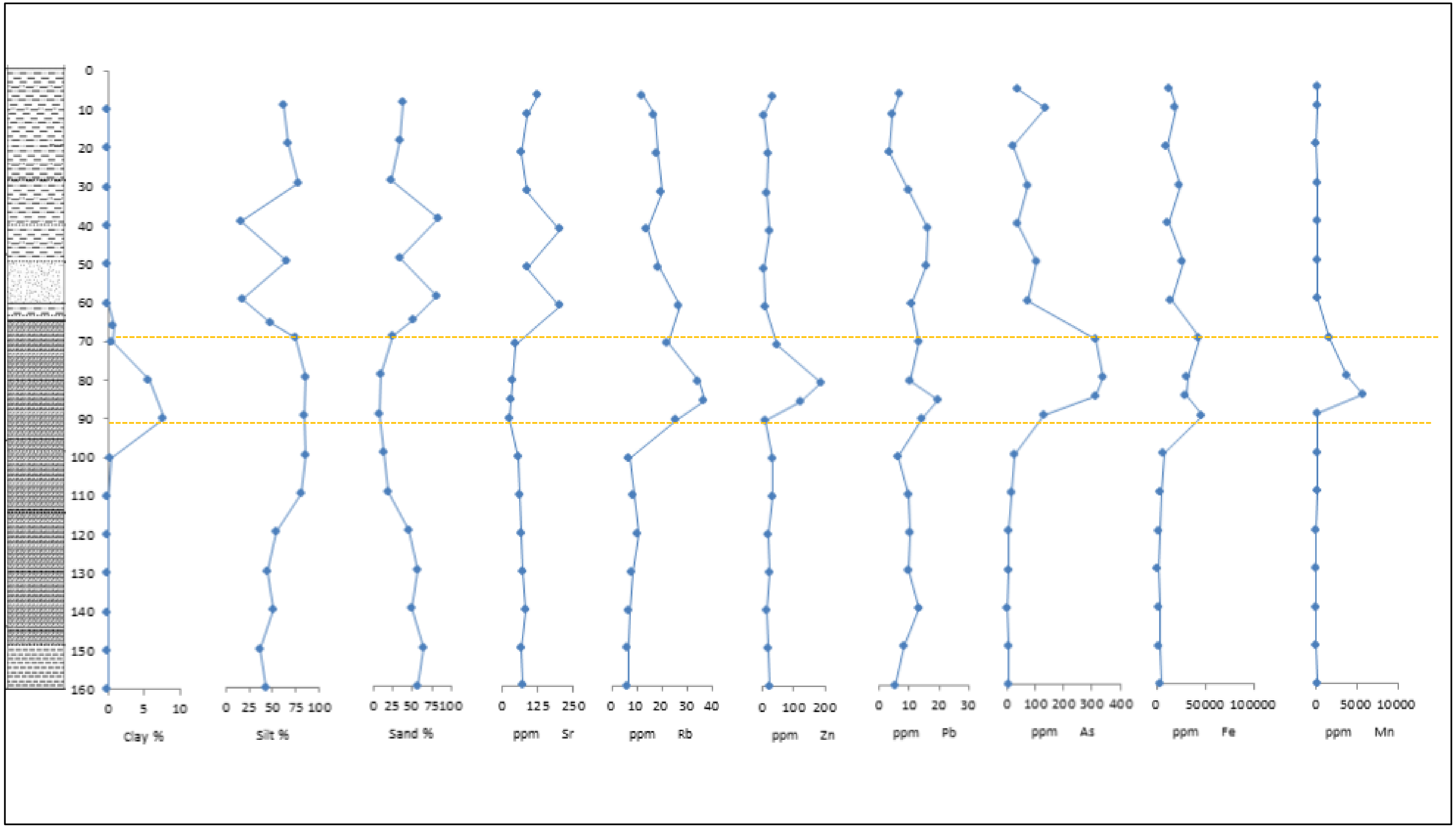


Figure 6.10: Kuaotunu 3 Core stratigraphy, PSA and geochemistry results. Orange lines represent where a potential 'mining' layer could be.

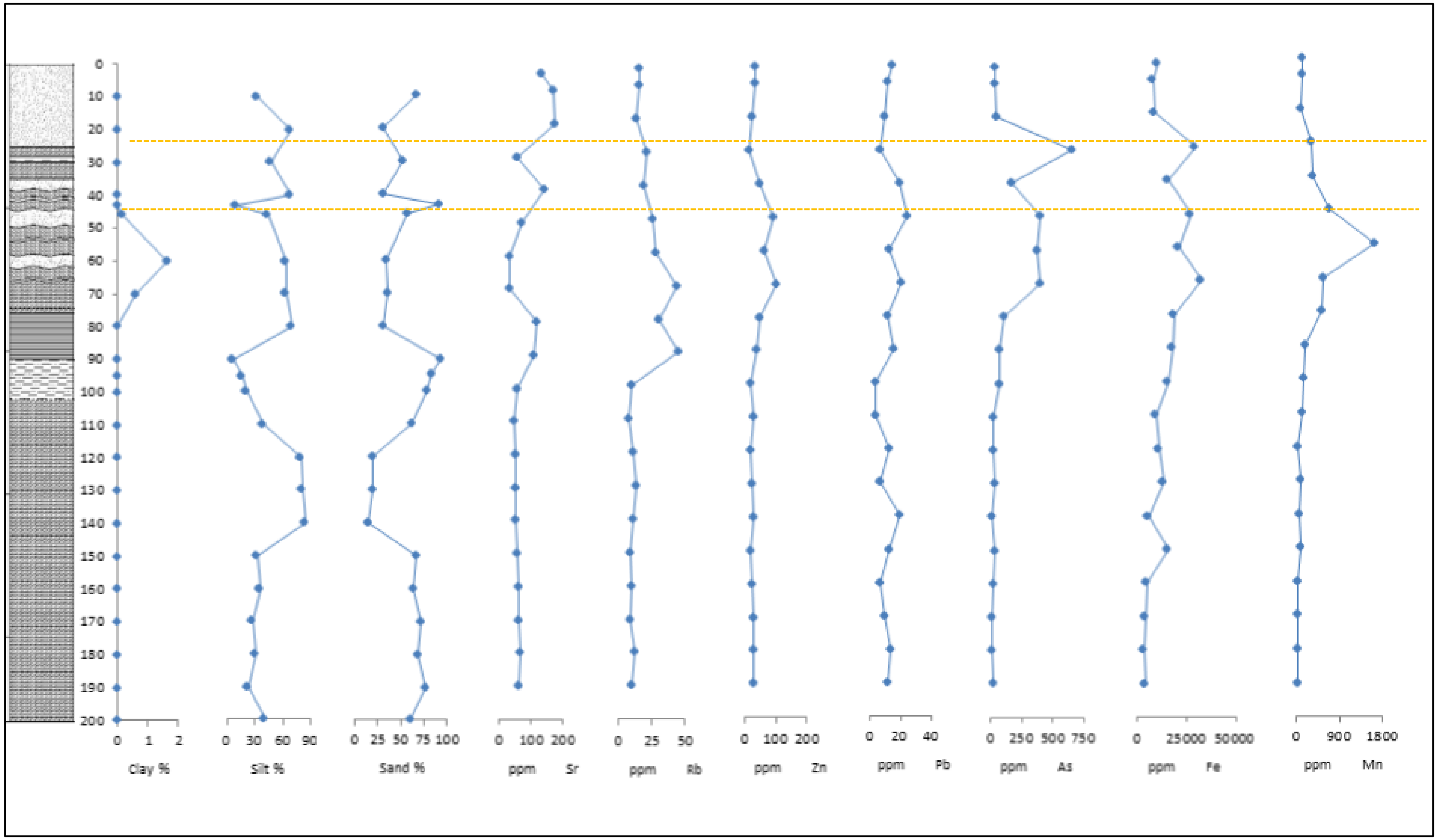


Figure 6.11: Kuaotunu 4 Core stratigraphy, PSA and geochemistry results. Orange lines represent where a potential 'mining' layer could be.

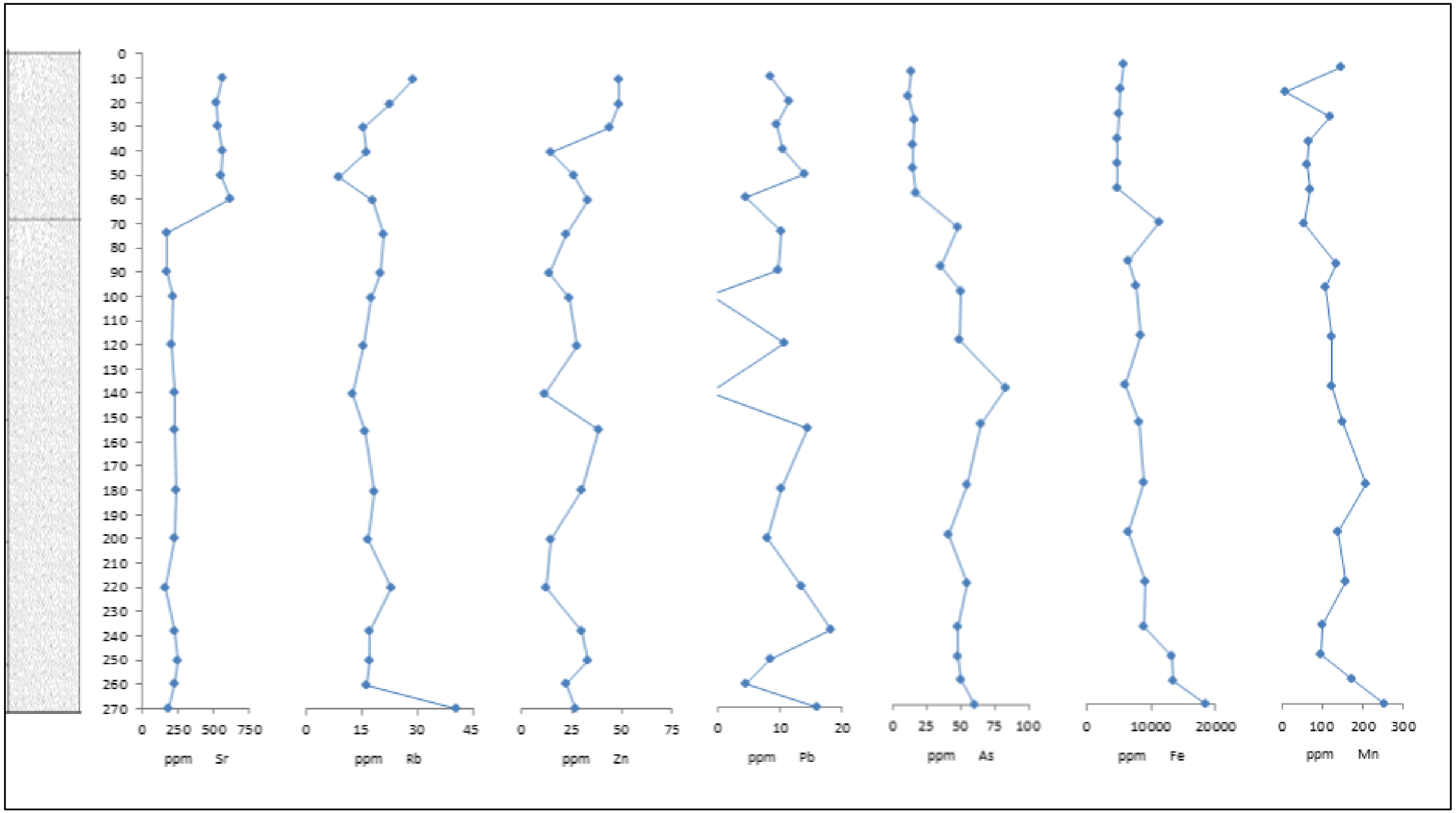


Figure 6.12: Kuaotunu 5 Core stratigraphy and geochemistry results.

6.3 Geochemistry Results:

XRF NITON analysis was conducted on all of the cores at Aberystwyth University, Wales by Ms. T. Novakova**.** Due to issues with the instrumentation the limited ITRAX results are only used as supplementary data and not the focus for this study as the same methodology can yield slightly different results, thus making the comparisons with each of the cores biased. The results of the XRF NITON analysis are shown in Figures 6.7-6.12.

6.3.1 Maori Road Core:

The NITON XRF showed a distinct change in abundance of the trace elements from 0.61 m to 0 m and from the base of the core to 0.61 m. From 0.61 m to 0 m, As and Pb increased suddenly, whereas they were relatively uniform from the base to 0.61 m in depth. Mn and Fe were uniform in abundance but at 0.61 m in depth to 0 m decreased in measured parts per million but maintained their fluctuating pattern. Zn increased steadily from 2.0 m with a peak at 1.25 m, decreasing from 0.61 m to 0 m. RB peaked at 0.5 m depth decreasing to 0 m.

6.3.2 Gerard Core:

The XRF NITON analysis observed significant peaks and/or drops for Sr, Rb, PB, Zn and Fe at 1.4 m to 1.25 m in an otherwise uniform spread of values. The results showed a peak at 3.0 m for As, but was otherwise relatively stable with minor fluctuations throughout the core.

6.3.3 Kuaotunu Floodplain Core:

The XRF NITON results for this core showed no significant change throughout the core with the except of As and Fe values at 1.4. m, where both elements peaked.. Pb was relatively stable from the base to 0.3 m, where it peaked with > 70 ppm. In then slowly decreased from 0.3 m to 0 m. Sr generally decreased from the base of the core to the top with minor fluctuations.

6.3.4 Kuaotunu 3 Core:

Peaks of As, Zn, Rb and Fe occurred at approximately the same depth of between 0.9 – 0.7 m with Sr values peaking just prior to this at 0.55 m. Pb had a slight distinguishable peak at 0.9 m but fluctuated throughout the core so was not entirely evident. Apart from the obvious peaks the trace element levels were stable throughout this core.

6.3.5 Kuaotunu 4 Core:

As had a small persistent peak from 0.7 m to 0.5 m, with the largest peak at 0.45 m, coinciding with an increased amount of recorded Fe. Sr was stable from the base to 1.0 m before fluctuating increasingly to 0.3 m.. Zn was stable from the base to its peak from 0.7 m to 0.4 m before becoming stable to the top of the core. Pb fluctuated throughout the core with no obvious trend. Rb was stable until its peak at 0.9 m.

6.3.6 Kuaotunu 5 Core:

The clearest change in geochemistry was apparent for Sr, where it sharply increase from0.6 m. Rb peaked at 2.75 m but otherwise was relatively stable. As and Fe were minor components but showed a general decrease above 0.5 m. Pb fluctuated with no clear trend with only minor amounts detected. Zn in general showed a drifting increasing trend from the base to the top of the core..

6.4 Age of cores & Sedimentation rates:

The sedimentation rates are presented in Table 6.6.

Core Name	Calculated Sedimentation rate pre-mining (mm yr-1)	Calculated sedimentation rate post-mining (mm yr-1)
Maori Road	0.35	5.26
Gerard Road	0.203	-
Kuaotunu Floodplain	-	2.456
Kuaotunu 3	-	7.895
Kuaotunu 4	-	-
Kuaotunu 5	-	-

Table 6.6: Calculated sedimentation rates pre and post mining for the six cores extracted from Kuaotunu and Paeroa.

The piece of wood located at 1.0 m in depth in the Gerard Road Core was dated as 6868±114 cal. yr. BC (see appendix 6.6). This gave an accumulation rate of 0.145 mm yr $^{-1}$. However, this has been corrected to 0.203 mm y^{-1} as it was found after sampling that the top 400 mm of the floodplain was missed. The core stratigraphy below this point (excluding the sharp transition boundary) was relatively uniform and has been interpreted as the sedimentation rate being relatively stable throughout the core with no distinguishable rapid or reduced accumulation of sediment evident. The exception was the distinct change in grain size and colour evident from the visual and PSA results at 1.3 m to 1.140 m in the core suggesting rapid accumulation of the material based on the large grain size and distinct transition at the base of this layer; however after this event it appeared the rate returned to the previous accumulation rate.

The other piece of wood located at 1.6 m depth in the Maori Road core was dated as 4001±28 cal. yr. BP. (see appendix 6.6). This gave an accumulation rate of 0.35 mm per year to this point. When the geochemistry and sedimentology results were taken into account it showed there was a distinct change at 0.6 m depth. If this is to be considered as the boundary between pre and post human occupation then this sedimentation rate should cease here with a new one established from this point forward using recorded human occupation history. In the wider Paeroa area mining commenced at a large scale at 1900 ± 10 years; therefore a sedimentation rate of 5.26 mm yr^{-1} could be established from this point forward to the top of the core.

The Kuaotunu Floodplain core, Kuaotunu core 3 and Kuaotunu core 4 had no material extracted for radiocarbon dating. Based on the peaks of chemicals and changes in particle sizes approximate sedimentation rates after human occupation have been deduced for these cores.

The Kuaotunu core 5 had no sedimentation rate calculated due to the lack of sediment changes observed visually in the core or any clear geochemistry patterns suggesting evidence of human disturbance.

Chapter 7: Discussion

7.1 Disturbance in the Coromandel

7.1.1 Maori Road Core

Of the six cores extracted, the signals of anthropogenic disturbance are perhaps most obvious in the Maori Road core. The transition from the pre-human, non-modified sediment record to the post-mining, intensive environmental change that occurred at the Coromandel is captured in the PSA and geochemistry results, which show a significant change at 0.6 m depth. Below this level there is a higher percentage of fine-grained, silt- and clay-sized particles, whereas larger, coarser sand particles of a light yellow-cream colour occur directly above. This marks a boundary where the environment at Maori Road had rapidly changed, and this is attributed to anthropogenic factors, as described below.

The sudden appearance of coarser and lighter-coloured layers in the stratigraphy of extracted cores or exposed river banks has been shown to indicate the rapid accumulation of sediment (e.g. Knox, 2000; Nanson, 1986). This is normally attributed to a high flow event (i.e. flood) where a larger amount of sediment becomes mobilised due to the increased stream power and compounding hydrological parameters causing movement of the bed and increased erosion, with the subsequent decrease of flow resulting in rapid accumulation of the mobilised sediment (Schumm & Lichty, 1965**,** Ritter *et al*. 1973; Knox, 2006**;** Dhivert *et al*. 2015). These particles tend to be coarser in size as the increased discharge can mobilise larger particle sizes thus forming thick coarse bands in the sediment record. Dhivert *et al*. (2015) illustrated this in a dam built in the Upper Loire River, France, where a 154 cm core was extracted from the deepest part of the reservoir. Three distinct, thick, light bands of sediment with coarse sandy grains were identified ranging from 6 to 20 cm in thickness, coincided with the 3 largest flows entering the dam since its construction in the early 1980s. This illustrated the rapid accumulation of sediment deposited after the flood waters receded. As shown by the PSA results for the Maori Road core, the percentage of large, sand particles suddenly increased at the 0.6 m boundary with the smaller silt and clay particles dominating below this depth. This distinct band is therefore attributed to such a flow event whereby sediment within the channel and upstream from this site had been remobilised and distributed across the floodplain, leaving behind the coarse material observed in the core. This band had a diffuse boundary to the top of the core as the material had become reworked which is a common occurrence as observed in other floodplain cores (Richardson *et al*. 2014).

Many studies have highlighted the increased thickness of flood bands within cores, and therefore increased erosion and deposition in the fluvial system, following initiation of anthropogenic activities such as agriculture and mining in surrounding areas (e.g. Ralska-Jasiewiczowa & van Geel, 1992; Knox, 2001; Xu, 2004; Vandenberghe *et al*. 2012; Manju *et al*. 2014). For example, Knox (2006) analysed floodplain stratigraphy to construct a floodplain history of the lower Mississippi and observed a distinct change towards coarser flood layers at approximately 175-200 cal. yrs BP. in the 6,000 year record, which coincided with the surrounding landscape transitioning into agricultural pastures and fields. This increased the annual sedimentation rate of the floodplains from 0.9 mm per year in prehistoric times to between 2 to 20 mm per year, with an increase in coarse, light coloured bands dominant throughout the upper core profile. With no other large distinct bands within the Maori Road core, this therefore supports the theory that anthropogenic factors have caused a disturbance at this site, resulting in increased sedimentation in the Ohinemuri floodplains.

However, the distinguishing feature of this coarse layer within the Maori Road core which further implicates anthropogenic change in the system, was the bright yellowish colour of the material which was evidence of heavy metals present (Morra *et al*. 2015; Macklin *et al*. 2006; Craw & Chappell, 2000). The NITON geochemistry results support these interpretations, showing a steady amount of measured Pb and As from the base to the distinct transition boundary at 0.6 m. Levels of Mn and Fe were relatively stable to 0.6 m, with the former fluctuating within a set range. Above 0.6 m levels of Pb and As peak , with Fe and Mn dropping (see Diagram 6.8). Changes in baseline geochemistry have been shown to be a clear indication of anthropogenic impact over time. Hudson-Edwards *et* al. (1997) found peak Pb, Zn and Cd were greater than 10 times that of the underlying trace element values at the Tees River Basin, Northern England as defined by Lee (1989) at the mining sites. Morra *et al*. (2015) observed in the Coeur d'Alene River, Idaho mining district (USA) from a 80 year sediment record that Pb concentrations peaked at just under 7,000 ppm (7 g kg^{-1}) at the height of the mining industries activity between 1943 and 1955 until the construction of a tailings dam reduced the input. Similarly Mn and As coincided with the peak of Pb within the lake, though Mn reached a peak of 10000 ppm (10 g kg^{-1}) later in 1968 and As peaking more recently above 1980 of 250 ppm (mg kg^{-1}). Pb concentrations in lake sediments extracted from southeastern USA also had a direct correlation with the cessation of lead ores used for gasoline extraction, where the Lead peaks were prior to 2,000 and began reducing to base levels, further highlighting the human disturbance to the natural geochemistry levels at sites (Escobar *et* al. 2013). The observed peaks in the Maori Road core therefore mirror prior studies conducted overseas in areas with a known sediment disturbance history, though not as drastically. This would most likely be due to the smaller scale of mining operations in the area compared with overseas (e.g. Endgland and USA).

Work by Sabti *et al*. (2000) in New Zealand on the river quality of the Tui, Tunakohoia, Waitekauri, Waihou and Ohinemuri Rivers downstream from the Te Aroha mining areas also revealed the changes and peaks in heavy metal concentrations, which were related to mining activities. The material generated at mining sites upstream migrated down through the river systems, changing the levels of trace elements found in the sediments. Concentrations of Cd, Zn, Pb and As were detectable as far away as the Ohinemuri River, with trace amounts still detected within sediments past the settlement of Paeroa, over 50 km from the sources at Te Aroha. This is similar to the trends in chemical concentrations observed at the Maori Road site due to its proximity to the Ohinemuri River system, illustrating that the anthropogenic activity of mining has impacted the environment. Work by Craw & Chappell (2000) on the Maratoto and Zaheen mine tailings in the Coromandel Peninsula indicated peaks in As, Pb, Zn and Cu in river sediments directly below deposited mine tailings. Craw & Chappell (2000) noted the importance of determining the 'natural' or background level of metals in the environment beforehand. At the Monowai mining area, it was relatively enriched in naturally occurring As (approximately 10% of the natural trace elements found at the site) as it was slow to oxidize and thus was retained in the surrounding sediment, though did increase in abundance during mining operations. This was noted by other studies conducted in the wider area (e.g. Ward *et al*. 1977; Pang, 1995). The geochemistry results at Maori Road below the distinct transition zone therefore highlighted the relatively stable environment prior to human occupation as all the natural trace element concentrations were steady or fluctuating within a set limit; at 0.6 m as described previously many peak and do not return to prior levels or patterns, further implicating that the environment was significantly disturbed and rapidly, with ongoing impacts and limited recovery occurring.

With the combination of the sedimentological and geochemical analysis in relation to the known human history at the site, the distinct band at 0.6 m in the core has been interpreted as a 'mining layer' whereby anthropogenic factors (i.e. mining) began drastically modifying the environment and therefore caused disturbance at the site. Using the radiocarbon date this core represented an environment with a slow accumulation rate of just 0.35 mm annually prior to human settlement. In the wider Paeroa area mining commenced at a large scale at ~1905, depending on the claim as discussed in Chapter 4. Two large flood events were documented in 1904 and 1907 which submerged the Paeroa township under 2 ft of water in some places (as stop banks weren't constructed at this point in time [Watton, 2006]) implying this was the most likely time this sediment layer would have been deposited across the floodplains. Using this layer as a proxy of the beginning of human mining disturbance at the site gives a sedimentation rate of 5.26 mm per year.. This is 20 times greater than the previous rate (0.35 mm per year) of sediment accumulation at the site, indicating that a large level of disturbance has occurred. This pattern of a dramatic increase in sedimentation has been observed in case studies across the world (e.g. Knox, 2001; Xu, 2004; Ahmed & Ismail, 2008). Wei *et al*. (2005) found in the Bohai Gulf that the accumulation rate of muddy sands had increased from 34.3 mm per year to 40.6 mm per year between 1955 to 1963. In the Yellow River, China, over the course of 2,300 years the sedimentation has changed from 4 mm per year pre 550 AD to 20 mm per year to 1850 AD. In the last 150 years it has increased up to 80 mm per year (Xu, 2003). In central coastal California sedimentation rates were impacted as early as 1770, increasing from 10 mm pre 1770, to 20 mm per year to the present (Plater *et al*. 2006). This strongly supports the suggestion that the change in sedimentation observed in the Maori Road core was related to anthropogenic disturbance in the form of mining activities at the site and in the wider region.

However, some studies have shown that shifts in climate can exacerbate or even be the true cause of disturbances in palaeo reconstructions of the environment (e.g. Rumsby & Macklin, 1994**;** Wilby *et al*. 1997; Gomez *et al*. 2004; Czymzik *et al*. (2010). Czymzik *et al*. (2010) reconstructed the 450 year flood history of Lake Ammersee, Southern Germany, where flood layers were distinctly seasonal; Czymzik *et al*. (2010) analysis showed that over the 450 year period the frequency distribution of floods was not stationary but was related to solar variability and changes to midlatitude atmospheric circulation patterns. This caused differences in flood layer thickness which was interpreted as differences in the magnitude of the floods entering the lake, with no clear anthropogenic factor causing the variation observed in the lake. Plangoen *et al*. (2013) modelled landuse changes in the Mae Nam Nan subcatchment over 10 years and found that human activities would not impact the predicted rate of erosion in 2040 as much as climate change, indicating that the latter has the greatest influence on the sediment budget within the region.

During the mining boom in the Coromandel in the late 1800s to early 1900s the climate was considered to be in a relatively stable state. Annual temperatures were approximately 0.8°C cooler than present with seasonal and regional rainfall patterns observed at a smaller scale than present (Salinger *et al*. 1995). In the early 1900s there were several fluctuations between El Niño and La Niña conditions, with the first cyclone to hit New Zealand in recorded history, Cyclone Wilma, in 1911. Large storm events have been shown to cause increased erosion and therefore increased sedimentation to river channels, lakes and floodplains but this is usually coupled with change in landuse patterns, such as deforestation allowing surface runoff to increase erosion in the area (Salinger *et al*. 1995). The PSA and geochemistry results are relatively consistent prior to the significant peak at 0.6 m, with the exception of a peak occurring at 2.05 m depth. When deducing the age of the record at 2.05 m point in time using the calculated sedimentation rate of 0.35 mm per year this peak would be at approximately 6430 cal. years BP. As discussed in Chapter 2, no humans would have been present in New Zealand at this time to cause changes to the physical or chemical composition of the landscape at this time, thus this fluctuation would be in response to a climate or natural disturbance shift. The peak at 6430 cal. yr BP is significantly smaller than the later peak in the core at 0.6 m, both in the sediment and chemical records. The larger peak occurring at 0.6 m in depth was at a time known in recent history to have human activities, specifically mining, deforestation and agricultural growth, occurring in the region. This further implicates anthropogenic disturbance as the cause for the sharp change of composition at 0.6 m, rather than climatic variations. Therefore with relative certainty the shift in sedimentation rates, change in sediment composition and fluctuations in geochemistry levels observed in the Maori Road cores can be attributed to human disturbance.

7.1.2 Gerard Road

The Gerard Road core has a distinct lighter layer from 1.33 to 1.21 m. At this layer not only did the physical grain size properties of the core change drastically, with a sharp increase in coarse, sandy particles and a decrease in silt and clay particles, but most trace elements analysed peaked at 1.3 m in depth. Unlike the Maori Road cores however this layer was discrete, with silt dominating the core above and below the layer, with geochemical levels of Sr, Fe, Mn, Zn and Rb returning to previous background levels after the peak. These combined results suggest that this layer therefore was not correlative to the Maori Road mining layer.

Distinct bands of lighter coloured sediments within cores, ranging from coarse to very fine in texture, that are not the result of flood events or even anthropogenic impacts maybe volcanic tephras (Lowe *et al*. 2012**;** Newnham *et al*. 1995). Pumice, ash, pyroclastic flows and volcanic glass are some of the material that is expelled during an eruption and becomes deposited within lakes, bogs and floodplains, creating a distinct layer which can be used to determine the age of surrounding material and to date cores and build up a timeline of eruptions or utilized for palaeoreconstructions (e.g. Lowe *et al*. 2008; Moriwaki *et al*. 2012, Davies *et al*. 2012). Using a record of tephra layers (i.e. tephrochronology) is applicable for cores extracted from New Zealand for correlating and synchronizing events in the country's history as well as determining the arrival of Polynesians to New Zealand, and thus when they first began disturbing the landscape (Lowe, 2012; Lowe *et al*. 2008; Sutton *et al*. 2008). The textural characteristics and trace elements identified in this layer suggested it may be a tephra layer. Centeno (2013) noted the sharp increase of Fe, Rb and Mn indicate a volcanic ash layer. After the eruption of Mt Saint Helens in 1980 the downwind geochemistry of the deposited material spiked in Rb, with previous eruptions also showing a greater amount of iron and manganese than baseline levels in the area (Lipman & Mullineaux, 1981). The dark greyish, coarse grading material also strongly fits the description by de Lange & Lowe (1990) of the Opepe Tephra layer; this layer, as described from the Kopouatai bog in the Hauraki Lowlands in New Zealand was derived from the Taupo Volcanic Centre and has been dated to 9991 ± 160 cal. yr. BP (Lowe *et al*. 2012; de Lange & Lowe, 1990). The radiocarbon date of

6868 ±114 cal. yr. BP at 1 m in depth suggests this tephra layer could fit the age range, particularly when considering from 1 m to 1.1m the coring tubes overlapped which caused compaction and reworking of the sediment. Other tephra layers dated around the Opepe tephra include the Rotoma 9423 +/- 120 and the Mamaku at 7940 +/- 257 cal. yr. BP. The former tephra age is older and could potentially represent this tephra layer however it's physical characteristics tend to be a light cream colour and hard, fine compacted lapilli whereas the latter is a bright yellow (de Lange & Lowe, 1990); neither matches the coarse grey grains observed in the Gerard core.

When considering the above results the Gerard core represents a stable environment with a very slow accumulation rate of 0.203 mm per year. There is a lack of evidence for anthropogenic factors impacting upon the sedimentation rate at the site. The largest floods in the area occurred in the earlier part of the 20th century which resulted in the decision to create stopbanks, so one would expect some sort of signature, as observed in the Maori Road core (particularly of the 1907 & 1910 flood events). However, an important consideration needs to be taken into account, particularly in comparison to the Maori Road core. Upon collecting the cores and completing the geochemistry and sedimentology results it was revealed that in the case of the Gerard Road core the top ~40 cm of the floodplain was not extracted. The location of the Gerard Road core was in a paddock and the core itself was extracted from a hollow, which most likely explains the lack of change within the core. As shown from the results, this floodplain had a slow accumulation rate, indicating a relatively stable environment. The core was old as shown through the radiocarbon date as well as the potential tephra layer. The area of interest in this core for this study therefore was most likely missed due to the location of where the core was extracted from and potentially its location outside of the stopbanks. The purpose of this study was to deduce if there was evidence of human disturbance at the site and unlike the Maori Road core this was not evident here.

7.1.3 Kuaotunu Floodplain core

Unlike the Maori Road and the Gerard Road cores there was no suitable material found within the core to radiocarbon date and therefore determine a chronology for this core. However, based on the geochemistry and sedimentology results a 'mining layer' similar to that described in the Maori Road core was evident within this core, though not with the same level of certainty as observed in the Maori Road core.

There was a distinct transition at the 0.6 m mark. Above this layer the sediment was a lighter colour with fine grained texture and minimal sand, whereas directly below, the particles were significantly darker with a gritty, silty sand texture. The PSA showed a slight decrease in clay particles with a trend of decreasing silt and increasing sand at this transition boundary.

The trace element results from the Kuaotunu Floodplain core show a distinct change, correlating to the PSA and physical description results at 0.6 m in depth. Below the transition boundary the measured Pb and As levels were relatively stable, with the exception of a peak in the latter at 1.75 m. At 0.6 m the amount of Pb peaked to the highest measured amount in the core as well as a similar drastic increase in As. Mn and Fe also increased slightly at this point though they fluctuated throughout the core so it cannot be clear that these observed rises were in response to mining contamination. During cyanide processing of ore rock, As is known to leach out of metal-bearing ore, causing peaks in the chemical during geochemical analysis downstream of mining sites (Hudson-Edwards *et al.*1997; Crecelius *et al*. 1975). Work in Mexico by Razo *et al*. (2004) observed that, in a 105 km^2 area where historical mining occurred, that soil samples surrounding the mine contained high levels of As that decreased downstream even after the mining operation had stopped in 1992, more than 10 years prior to the study. Lingering peaks in As have been observed in multiple studies as evidence of mining in locations and persevering decades after the cessation of the activity (e.g. Williams, 2001; Taschereau & Fytas, 2000) and is therefore a reliable indicator of human disturbance, in the form of mining activity, at a site.

Based on these results, combined with the PSA, it was interpreted that this boundary layer marked the 'mining layer' within the Kuaotunu core, when human activities caused large scale disturbance at the Kuaotunu Floodplain site. However, unlike the Maori Road core, trace element values reverted back to near pre-human disturbance levels. The peak in AS and Pb reduced back to the previous levels in the core. This is in contrast to previous studies on geochemical analysis of mining-impacted reaches (e.g. Owens & Walling, 2002; Velasquez-Lopez *et al*. 2010) where after mining the changes in trace element levels do not revert back to amounts pre-disturbance. There may be two explanations for the lack of continued higher concentrations of chemical contamination than in pre-disturbance times in the core: no significantly large overbank flow events have occurred since the early 1900s, precluding deposition of sediment contaminated by mining byproduct chemicals; or alternatively that the subsequent and ongoing soil erosion in the catchment has effectively 'capped' the mining waste here, so that it is not being reworked, but rather is being buried by new sediment. The first suggestion does not seem plausible as there have been multiple large scale storm events causing flash flooding in the region since the 1900s (Salinger *et al*. 1995) that have caused flooding of the local floodplain. The latter explanation therefore seems more appropriate. Contaminated material can be 'capped' by overlaying clean sediment to reduce or stop reworking, in order to contain the contamination. This can occur naturally through large flood events, or artificial capping layers can be implemented. Simpson *et al*. (2002) observed in estuarine environments that when there was at least 5 mm of clean sediment introduced into the environment, it reduced zinc influxes from the contaminated sediment below into the water column. Ideally, 300 mm of clay sediment would bring the most benefits, as burrowing organisms had the potential to break through thin caps and allow zinc to infiltrate the clean sediment above. Reible *et* al (2006) compared the effectiveness of clay versus sand capping layers in the Anacostia River, Washington, USA. Though the clay layer was more impermeable and had the least seepage of contaminants over a 24 month period, contaminated sediment was detected on all top layers due to the continued pollutants entering the system. This is applicable to the Kuaotunu catchment. The PSA and geochemistry results suggest that the contaminated sediment has been capped, preventing rworking of the sediment. Furthermore, with the ceasation of mining in the area, there is no new contaminates entering the system, thus no peaks of trace elements after the initial disturbance. In contrast, the Ohinemuri had a larger scale mining operation, no natural or artificial capping layer, and continued reworking of the sediment. This caused long term changes to the sedimentology and geochemistry unlike in the Kuaotunu catchment.

On the basis of the explanations presented above, the changes at 0.6m depth core can be interpreted as the 'mining layer'. Therefore, a sedimentation rate could be calculated for the Kuaotunu Floodplain core. Mining first began in 1890 at the Kuaotunu sites, with the largest floods during this mining time occurring in the Coromandel region in the early 1900s. Approximately 0.28 m of sediment accumulated above the 'mining layer'; using an approximate age of deposition of 1900 ± 10 years gives a sedimentation rate of 2.456 mm per year. Since there was no age control determined for the core below this layer the change in sedimentation rate cannot be deduced for this site and thus it cannot be determined whether or to what extent the sedimentation rate has increased, decreased or remained relatively stable since disturbance.

7.1.4 Kuaotunu 3 Core

The Kuaotunu 3 core was extracted using a vibracorer as it was extracted from the channel of the Kuaotunu Stream. Most interestingly are the similarities this core exhibits with the Kuaotunu floodplain core, albeit at different depths due to the differences of reworking within the channel in comparison to the deposition during high energy flood events on the floodplain.

The most striking feature of the core was the distinct sandy layer at 0.63 m to 0.52 m. The PSA results shows a sharp rise in sand, a decrease in silt and little clay particles. Interestingly this sharp rise is also observed higher within the core at 0.4 m in depth, yet the observed grainy texture was not evident during visual logging of the core. Below the distinct sand band was another minor band of sand from approximately 0.678 m to 0.664 m, before the smaller clay particles decreased from 1.0 m to 0.7 m in depth. This appeared to be the result of a large flow depositing large granular material as flow decreases after the peak, leaving behind a layer of larger grained particles (Knox, 2006; Bridge, 2002). Similarly to the Kuaotunu Floodplain core, the amount of smaller, clay sized particles also coincided with the peaks in certain trace elements. Pb and As, along with Fe, Mn, Zn and Rb all show peaks at 0.9 m in depth. Similar to the Kuaotunu Floodplain core, after the peak these elements returned to pre-peak levels, suggesting contamination was during a short period with limited long term impacts of mining by-products as they became buried over time.

If the peak of the trace elements measured at 0.9 m represents the 'mining layer' as observed in other cores of this study, it would give this core an approximate sedimentation rate of 7.895 mm per year. Similar to the Kuaotunu Floodplain core, there is no way to deduce the pre-human sedimentation rate within this area. However, this core was extracted from within the channel of the Kuaotunu Stream, with sediment accumulating significantly differently than in a floodplain. Within a river channel, factors such as discharge, stream power, channel area, the threshold for bed movement and available material for mobilisation all impact the amount of scour and deposition in channel, which impacts the rate of aggradation and/or degradation within a reach (e.g. Bathurst, 1997; Batalla & Martin-Vide, 2001). Over time, rivers have shown to change scour and deposition patterns, which may result in zero net accumulation. For example, Stanley *et al.* (2002) observed that within one year of dam removal on the Baraboo River, Wisconsin, downstream sites approximately 3.5 km away had increased annual sediment accumulation to 25cm, compared to just over 10 cm the year previously. However not all sites saw an increase in sediment accumulation, with some sites along the reach experiencing a drop as the material was remobilised and deposited elsewhere, meaning depending on which site was used would give a different overall accumulation rate. Leopold (1973) observed over a 20 year record on a section of the Watts Branch basin, Maryland, that for the first 12 years the channel became narrower and smaller until it crossed a certain threshold where rapid accumulation of sediment subsequently occurred. Yet despite the trend of increasing cross-sectional area observed in the later years, the overall net result after the total 20 years was that the channel had become smaller by 20 percent. This highlighted the importance of time scale when looking at a reach, as initially it appeared the channel was shrinking yet in the later years it was rapidly expanding. Therefore, depending on the time-scale and locations used can give varying answers as to how a river is changing over time. This is due to their unstable nature in comparison to floodplain environments.

The peak in trace elements within this core however cannot be interpreted as anything other than human interference. While there is some uncertainty around the true sedimentation rate within the Kuaotunu channel mining has clearly impacted the site. In contrast to the Maori Road cores but similar to the Kuaotunu floodplain cores, this disturbance was at a much smaller scale with shorter-lived impacts on the environment and subsequent return to background levels. The results in this core therefore give support for the conclusions drawn from the Kuaotunu Floodplain core albeit at different depths, due to channel processes impacting reworking and sediment depositional processes.

7.1.5 Kuaotunu 4 Core

This core was extracted using a vibracorer several metres away from Kuaotunu core 3. Due to the close proximity of these cores it was expected that a similar pattern would be observed as in the other in-channel core and floodplain core. This was not clearly evident based on the particle size and geochemical analysis.

The particle size analysis revealed a clear peak in clay at 0.6 m in depth but was still of a negligible amount (2%) compared to the overall core. Abundance of silt and sand fluctuated through the core, with four clear transition zones: at 1.5 m silt suddenly increased with sand decreasing; 1.2 m in depth with sand increasing and silt decreasing; 0.9 m with the reverse occurring; and the last peak of sand and decrease of silt at 0.4 m. The PSA did not pick up thin yet visible bands of sand throughout the core from 0.7 m to 0.4 m. These distinct bands are evidence of flood-deposited layers (e.g. Ambers, 2001; Knox, 2006; Dhivert *et al*. 2015). There is somewhat of a correlation between the PSA results and the trace element analysis, though this is not as evident as it is in the other extracted cores. Rb first peaks sharply before tapering off at 1.05 m yet Zn and As do not increase until 0.8 m in depth, which coincides with the steep decline in sand and rise of silt in the record but precedes the rise of clay. Pb also does not rise to its peak until 0.6 m coinciding with the peak of clay particles. Mn peaked both after As and Zn began to rise when sand particles had already decreased and silt increased. This could be interpreted as evidence of reworking, as the changes in sediment characteristics do not line up as clearly as would be expected.

Reworking within a river channel is the process where material is moved and altered from its original state, such as material deposited from a landslide and transported downstream, potentially changing in shape and size along the way (Hooke, 2003; Smith & Rodgers, 2009). This can cause once distinct layers of material to be shifted within the channel and intermixed with other layers, resulting in homogenisation and loss of clear signals of events within the record. Reworking is therefore a common issue when reconstructing palaeoenvironments (e.g. Atkins & Dickinson, 2007; Rucker & Snowden, 1990; Holbrook & *et al*. 2006). In the Skahit River tidal zone, the river was transporting large amounts of muddy sediment out of the catchment, with little to no amount of it was observed within the tidal flats, which were predominantly sand. It was that found during high flows the sand bed was stirred up along with the smaller mud particles and when the flows subsided the larger sandy particles would be deposited again but the mud would remain suspended and transported out to sea (Webster *et al*. 2013). Ralston *et al*. (2013) observed that the combination of fluvial processes such as the high and low flows with estuarine processes like the ebb and flow of the tide greatly impacted the trapping of sediments and therefore the composition of sediment particles within the environment. The proximity of the Kuaotunu cores to the river mouth are within 1 km, therefore the environment can be impacted by tidal processes along with those operating in the fluvial environment. The impact of ocean processes impacting this location is further shown by the presence of shells within the core, indicating one of two things; that the conditions are suitable of marine life or secondly further suggesting reworking has occurred. This would result in a higher amount of reworking occurring within the channel compared to non-estuarine impacted environments and may explain the non-cohesiveness of the particle and geochemical results (in contrast to the other cores) observed within this core and the other in-channel core results.

Though the sedimentological and geochemical variations observed in Kuaotunu Core 4 are not as strong as in the Kuaotunu Floodplain core and Kuaotunu 3 core, it still shows evidence of human disturbance due to peaks in Pb, As and Rb trace elements, which are attributed to mining within the wider region as described previously. Due to the evident reworking of the materials within this core, a sedimentation rate was not calculated as it was unclear at which depth the layers were deposited before being reworked. Therefore this core should be used as supplementary evidence to the Kuaotunu Core 3 as that it further showed mining contamination.

7.1.6 Kuaotunu 5 Core

This core was extracted using the vibracorer within the estuarine environment where the Kuaotunu River flows out into the ocean. Unlike the previous cores however there was no clear evidence of anthropogenic factors causing disturbance, though this is most likely due to the location of the core.

The core consists of sand with shells identified as *Austrovenus stutchburyi* found throughout the core. No PSA was conducted due to the uniformity of the core in terms of sediment particles and colour changes. The geochemistry results showed no clear pattern for any of the chemicals except a rise in Sr at 0.6 m and a peak in Rb at 2.7 m. Based on these results this core did not capture disturbance at the site triggered by mining.

This result is not unexpected since the core was extracted from the river mouth. It has been shown that sedimentation rates can increase closer to the river mouth, causing progradation outwards (e.g. Healy, 2002; Swales *et al*. 2007). Within the wider Coromandel region sedimentation rates are significantly high close to the coast. Swales *et al*. (2007) observed at the Firth of Thames estuary, located on the western side of the Coromandel Peninsula, following catchment deforestation from the early 1850s the sedimentation rates have increased to nearly 100 mm per year. This has caused expansion of mangroves in the wider area to nearly 1 km seaward from their original habitat location. When reconstructing this environment tens of metres of cored material was required to deduce where the change had occurred (using trace element results) due to the high accretion rate in the area. This area is notorious for its high sedimentation rates with numerous studies conducted on it (e.g. Naish, 1990; Young & Harvey, 1996). Large sedimentation rates are also observed on the east coast of the North Island, New Zealand in places such as the Ohiwa and Whangarei Harbours (Healy, 2002), meaning long cores would be needed to capture the time period of first human occupation to an area. The core extracted from this location in the Kuaotunu River was 3.1 m in total depth; based on previous studies conducted in similar environments around New Zealand this would not be sufficient to capture evidence for mining in this catchment.

7.2 Anthropogenic disturbance in New Zealand

The cores extracted from the Paeroa and Kuaotunu areas show that after the arrival of Europeans to the area the landscape has been modified, leaving behind a notable change to the environment. This study has focused on the impact of mining in both of these areas in the form of changes to the baseline amounts of trace elements present, and increased sedimentation in the region. Of particular importance is that the larger the scale of disturbance, the greater the initial impact and long-term impact to the environment, as shown by the increased disturbance at Paeroa in comparison to Kuaotunu. This result has further added to the growing studies conducted in both the North and South Islands of New Zealand indicating that anthropogenic factors have led to rapid modification of the landscape, causing significant disturbance to the once pristine environment. It has also highlighted the speed of disturbance in the area. As observed by Wilmshurst (1997), Reid & Page (2002), Lovelock *et al*. (2007) and Hughes *et al*. (2012) following European settlement to an area greatly increased the amount of disturbance, with greater increases in sedimentation rates, peaks in new exotic species displacing native populations and changes in hydrological regimes due to increased sediment causing changes in morphology of areas. Glade (2003) has noted that sedimentation rates have increased of up to nearly 18 fold since Europeans began forest clearance on slopes, resulting in increased erosion rates and sediment levels in rivers, lakes and swamps. Mining in particular is a very damaging activity, as it involves forest clearance and causes changes to the natural trace element signatures in the environment. This has flow on effects, altering fluvial regimes with increased or decreased sediment and water quality contamination impacting indigenous species (Sims & Francis, 2008; Manju *et al*. 2014; Dhivert *et al*. 2015). In comparison, prior to European settlement the greatest amount of disturbance by Polynesian settlers was mainly constricted to the coast and open flat land, where the vegetation was burned and replaced with large amounts of fern bracken (Newnham *et al*. 1998).

The Paeroa and Kuaotunu cores support this observation of Polynesian settlers not significantly impacting the fluvial sedimentation regime in the Coromandel. This is shown by the lack of variation in trace element concentrations and sediment characteristics prior to European settlement. That is not to say that early settlers were not causing disturbance in the Coromandel region. Byrami *et al*. (2002) observed that Polynesians had been in the Kauaeranga valley adapting the environment from as early as 750 cal. yr. B.P. based on the abrupt rise of *Pteridium* coinciding with charcoal. This is similar to other areas of New Zealand such as the eastern Hawkes Bay and Northland regions where peaks of fern bracken with charcoal are the main indicators of Polynesian disturbance (e.g. Elliot *et al*. 1998; Wilmshurst *et al*. 1999; McGlone & Wilmshurst, 1999; Ogden *et al*. 2003). Work by McWethy *et al*. (2010) in the South Island observed that after peaks or changes in charcoal levels, vegetation patterns in the local region were altered, indicating rapid land disturbance. In contrast to what was observed in Paeroa and Kuaotunu, Page & Trustrum (1997) observed a 60% increase in sedimentation rates in Lake Tutira following Maori arrival, indicating that in this region the clearance of native bush on low hillslopes with fern bracken did cause a change in the sediment regime. This highlights that due to differences in topography, hydrological systems and vegetation patterns, anthropogenic disturbance of an area is variable in magnitude.

McWethy *et al*. (2010) highlighted the importance of topography particularly well with multiple sites across the South Island. The sites situated at high altitudes with greater than 1600 mm of annual rainfall showed the most resistance to burning, and therefore Maori disturbance, to the areas whereas mid- to low-altitude, low rainfall sites were nearly completely converted from closed canopy forests to open grass and tussock lands. The compilation of North Island disturbance studies did not have this similar trend where altitude and rainfall impacted the amount of disturbance, but rather the amount of human activity in the area (refer to Figure 3.4). This work in the Coromandel agrees with the observations across the North Island; the region experiences historically less than 1200 mm of rainfall annually (Metservice, 2014). However, the region contains steep slopes with little clear flat areas restricted to small margins near the coast (Adams *et al*. 1994) which may have restricted early Maori forest clearance of the area, particularly in the Kuaotunu catchment, further reinforcing the observations in the North Island and a conclusion by McWethy *et al*. (2010). The Paeroa area in contrast is more accessible with a generally flatter topography. Byrami *et al*. (2002) observed in the Kauaeranga valley, which is east of Paeroa, there were rapid changes in vegetation patterns and charcoal present from extracted lake cores, which is evidence of disturbance in the area. However, with the arrival of Europeans to both of the areas disturbance was evident, implying that though Maori settlers may have first begun disturbing the New Zealand landscape, the European impacts were on a significantly larger scale. Therefore the results from Paeroa and Kuaotunu not only further give support to rapid disturbance occurring in New Zealand following European arrival but also highlighted the differences the geography of an area contributes to the rapidness and amount of disturbance that can occur in an area. As illustrated in Figure 3.3 the underlying geology may play a part in allowing sediment to become more mobilised if it is of a weak nature that is susceptible to erosion, though any removal of vegetation to an area will increase this on all geology types. What is common to all disturbance studies conducted in New Zealand are the rapid changes to the environment following either the first Maori wave or later European wave of immigration to the islands (Sutton, 2008; Striewski *et al*. 2009; McWethy *et al*. 2012).

7.3 Use of Geochemistry and Sedimentology

7.3.1 Geochemistry and sedimentology in New Zealand studies

In New Zealand, the majority of studies concerned with disturbance have focused heavily on using the changes in vegetation patterns to deduce the impact humans have had on the environment (e.g. McGLone, 1983, McGlone, 1989; Newnham *et al*. 1989; Bussell, 1998; Horrocks *et al*. 2001). However, the combination of palynological studies with either geochemistry or sedimentological results has helped to validate the conclusions drawn from the palynological research. This has enabled better understanding of the disturbance following human occupation to an area. Elliot *et al*. (1997) highlights this very well with work done on cores extracted from the Wharau Road Swamp situated in Northland, New Zealand. Major forest disturbance occurred at 600 cal. yr B.P. where a peak of charcoal was noted alongside a rise in *Pteridium esculentum* and decreases in *D. cupressinum* and *A. lucida* The sedimentological results coincided with the vegetation changes with an increase of coarse grain-size fractions from 700 cal. yr. B.P. with the levels of K and Na concentrations increasing; the latter increased by more than four times of the amount detectable in dry sediment than the natural background levels, with the former doubling in milligrams per gram of sediment (Elliot *et al*. 1997). This gave multiple lines of evidence of human disturbance at the site and helped to distinguish the changes observed at the site from possible climatic fluctuations rather than in direct response to landscape modification.

A more recent study by Richardson *et al*. (2014) further supports the use of multiproxy studies using methods other than palynology. Using LiDAR data, sedimentology, radiocarbon dating, XRF geochemistry analysis and Ground Penetrating Radar (GPR) on the Kaeo River, Northland New Zealand distinguished the pre- and post-settlement alluviation of the surrounding floodplain of the river to discern the anthropogenic impact in the area. Based on the combination of these proxies rates of 8-13.5 mm per year of accumulation were determined. This mirrored the general trend in Northland of rapid accumulation of the floodplains, where an average of 3-10 mm per year was observed. The grain-size analysis combined with GPR helped to distinguish boundaries of transition zones for the area, where old river channels and previous estuarine environments were situated. The XRF geochemistry analysis showed baseline trends and where changes occurred in response to both climatic driven and anthropogenic changes to the environment occurred. The combination of proxies therefore were vital in distinguishing the history of the area and determining the changes in sedimentation boundaries and what was the result of climate or human induced change to the environment.

The use of multiple proxies at the Paeroa and Kuaotunu sites therefore allowed greater interpretation of the histories of the areas and therefore the timing and degree of disturbance that occurred. The PSA results show clearly for the Maori Road and Gerard Road cores that sedimentation changes have occurred in the floodplain. The increase in coarse, larger grains observed above 0.6 m in the Maori Road core indicated that a change in the sedimentation processes had occurred, showing more sediment was deposited across the floodplain surface and at a larger scale and rate than in the previous history of the site. However, the XRF analysis allowed these changes to be more robustly correlated with anthropogenic disturbance; large scale storm events could easily cause mass landslides in such steep catchment areas, depositing large amounts of sediment available for transportation under flood conditions and end up as a distinct, large layer in downstream floodplains (Knox, 2000; Hooke, 2003). The clear rises of Pb and As from base levels therefore supported the claim of anthropogenic interference, as these are chemicals associated with mining and therefore would not have occurred naturally in the environment at such high levels.

It could then be argued that XRF results on their own would be enough to come to conclusions as to the amount of change at a site. The results from the Gerard Road core suggest otherwise. The sharp spike in all measured geochemical elements at a glance would indicate clear interference to the environment but without the physical and PSA results of the sedimentology the wrong conclusions could be drawn. The distinct increase in grain size and colouring of this layer, coinciding with a peak in trace elements, indicates that it is not a flood layer containing materials flushed down from a mining site as seen in the Maori Road and Kuaotunu Floodplain core, but rather a tephra layer. These can also be used to infer changes at the site and act as an age control for the region of interest (Lowe *et al*., 2000; Lowe *et al*. 2012) and were used to deduce an approximate sedimentation rate for this environment, giving evidence of the stability of the site prior to human occupation. Therefore the use of these proxies should be utilized in more New Zealand studies as results so far, including this study, indicate their usefulness and practicality in deducing anthropogenic disturbance at multiple sites.

7.3.2 Geochemistry and sedimentology as proxies for disturbance reconstructions

The use of geochemistry and sedimentology as proxies for disturbance reconstructions in the form of XRF analysis and PSA have been shown to be reliable to use to make inferences about human induced changes across the world (Croudace, 2006; Rothwell & Rack, 2006; Ene *et al*. 2009). Sim & Francis (2008) studied Hg and CN- transportation downstream from a milling processing plant to great success, illustrating the use of tracers within contaminated soils as a way to determine the environmental impact of industrial practices. Roulet *et al*. (2000) found that increased erosion led to increased Hg and changes in sediment characteristics in the Tapajos Rivers following deforestation of the Amazon forest. The peak in Hg confirmed the timing of deforestation beginning in the 1950s, illustrating the resolution of geochemical results. Using XRF NITON analysis has shown to be just as reliable as conventional analytical techniques such as electrochemical methods, chromatography separation and spectroscopic techniques, including analysis by atomic absorption spectrophotometry (AAS). Radu & Diamond (2009) observed in the Silvermines area, Ireland, handheld XRF NITON instruments had excellent correlation with the laboratory-based reference AAS method. Pb, As and Zn values showed the same fluctuations and approximate values as one another. The results of the measured Pb were exceptionally good, with R^2 values of 0.995 and 0.996 for the XRF and AAS measurements respectively. The limitations of the handheld unit over conventional lab based analysis techniques included the reduced detection of low Z elements. These required lower energy fluorescence lines. Also it required the samples to be homogeneous and representative material to ensure the results would be accurate. For further discussion on the strengths and weaknesses of this methodology can be found in Palmer *et al*. (2009). Overall, this implies that the use of this method on sediments extracted from the Paeroa and Kuaotunu areas would be sufficient to measure the fluctuations of the trace elements in the sediment. This is because the cores were measured as distinct sections (0.05 m intervals) with chemicals of interest measured using the same equipment in multiple studies.

The use of PSA to determine sediment characteristics is well documented, with changes noted in response to human and natural events (Knox, 2001; Owens & Walling, 2002; Glade, 2003; Richardson *et al*. 2013). Knox (2006) used PSA along with several other proxies to determine the sedimentation rate that was naturally occurring within the Mississippi River system. He then compared this rate after heavy agricultural modification occurred in the upper and middle reaches of the catchment. The coarse grain size layers determined by pipette and hydrometer methods for clay and silt fractions and sonic sifting for the sand fraction were correlated with the known flood history. This was used to deduce the sedimentation rates between each event, with a general accumulation rate over time calculated before and after human modification. A similar method used for the Paeroa and Kuaotunu cores was done by Owens & Walling (2002) to deduce sedimentation changes over a 100 year period in Scotland. Subsamples were extracted from the cores from the floodplain where the particle size was measured using a laser diffraction granulometer. It not only used this information to determine sediment entering the system with a flood and to calculate overall increases or decreases in sedimentation, but also where the sediment was coming from based on the surrounding geology of the land. Furthermore it revealed that the changes in sedimentation were attributed to human impacts based on where the sediment was derived from (i.e. from an agricultural dominated area meant the observed increase could not be attributed to climatic shifts, as prior to 100 years ago the area of interest was not agricultural land). Therefore the use of PSA for determining sedimentation rates and changes in response to anthropogenic factors is well documented.

The main disadvantage that can occur, which was observed for some of the Paeroa and Kuaotunu core subsamples and summarized in Tables 6.1-6.5, is the potential for flocculation of the samples. Eisma (1986) and Halverson & Panzer (1980) described how this can lead to misrepresentation of the measured grain size in the sample due to the particles clumping together. However the results obtained from the laser scanner were relatively appropriate for the environment that the cores were extracted from. The surrounding floodplain of the Kuaotunu area is comprised of a top soil of Loamy Sand due to the dominance of sand in the area followed by silt and low amount of clay, most likely transported from the higher reaches of the catchment (LRIS Portal, 2015). The Paeroa cores in comparison are described as a sandy loam with a greater mixture of sand versus silt (LRIS Portal, 2015). The PSA results obtained from the cores reflected these results reasonably well, with sand a dominant component. More silt-sized particles were recorded in the subsamples than might be expected in the Gerard Road and Maori Road cores at lower depths; this may be attributed to the upper catchment of the Ohinemuri River containing larger amounts of silt-sized particles, resulting in deposition of this material forming the floodplains thousands of years ago. The large amount of silt particles detected in these samples are not interpreted as evidence of flocculation of the samples congregating together, as the amount of clay sized particles is appropriate for the wider area. This suggests that at deeper depths silt is more prominent than sand sized particles in the top soil. With the exception of a higher amount of silt particles observed than sand particles within the Paeroa cores, the PSA results showed clearly the changes that occurred to the Ohinemuri floodplain in response to mining. It further suggests that it is an applicable proxy to interpret changes of the environment in response to anthropogenic influences.

Chapter 8: Conclusion

The arrival of humans to New Zealand has resulted in significant disturbance to the once pristine environment, as illustrated with the compilation of disturbance studies across both the North and South Islands. In the North Island, of 66 sites, only 15 did not show evidence of human-induced disturbance. In many cases these were sites located proximal to others that showed such evidence, implying factors such as resolution of the samples and purposes of the studies may result in disturbances not being determined, highlighting the importance of conducting multiple studies to verify changes in the environment. Geology and rainfall do not significantly alter disturbance in the area, with the compounding factor of human interference ultimately causing the rapidness and long term effects of disturbance to an area.

In the case study presented here in the Coromandel, the anthropogenic impact of mining in particular has not only caused significant disturbance to the fluvial system in regards to the amount of sediment being displaced, but has changed the geochemical composition of the sediments as well, changes which persist within the system long after the processes ceased. In the Paeroa area the two cores showed that prior to human settlement the floodplain was in a stable state, with sedimentation rates approximately 0.203 - 0.350mm/yr. After human occupation in the wider region this increased to 5.260 mm/yr, more than 15 times the previous rate of accumulation. Furthermore the geochemistry of the floodplain changed, with significant increases from baseline levels of As and Pb. In comparison the Kuaotunu floodplain accumulation after human arrival was 2.456 mm/yr, with the in-channel accumulation rate higher at 7.895 mm/yr, though with no age control for these cores it is unclear whether this amount of accumulation is an increase or decrease to the environment. The differences reflect the variations in catchment sizes between the two fluvial systems and the amount of mining that occurred in the two areas. The results suggest that short term negative environmental impacts will have less of a signature in the long term history of a small, steep, flashy discharge catchment, with the Kuaotunu cores showing that the geochemistry of the sediment reverted back to near pre-human levels whereas the larger Ohinemuri catchment has remained altered. The results observed at the two sites support previous work conducted in the North Island as well as the South Island of New Zealand where disturbance was rapid in response to human arrival and subsequent modification of the landscape, but also the longevity of human occupation determines the amount of disturbance and its lasting impacts in the environment. The use of geochemistry XRF Analysis and Particle Size Analysis of the sediment from the extracted floodplain cores highlights the usefulness of these proxies that are relatively underutilized in New Zealand disturbance studies and that they can be very helpful in determining when humans began disturbing the environment.

Chapter 9: Future Recommendations

To further validate the results described in this project the following future recommendations would be applicable:

- Combine all palaeo reconstruction results from the South Island to the study by McWethy *et al*. (2010) to further compare the results collected here from the North Island disturbance studies, as excluding different types of proxies may paint a different picture of the disturbance in this area. This would enable greater comparison between the North and South islands of New Zealand, generating a nationwide disturbance story
- Continually adding to the North Island Review that has been started here, to further validate the spatial and variation of disturbance across the North Island, and in conjunction with the South Island to describe accurately and in detail the disturbance history of New Zealand as a whole.
- Create a high resolution palynological record alongside the cores extracted from the Ohinemuri and Kuaotunu floodplains to determine if the vegetation patterns match the observed changes in sedimentology and geochemistry at the sites. This would further give agreement or disagreement in the conclusions made from this study about the rapid rate of disturbance in response to human modification to the environment and also may reveal changes to the environment from the first settlers, the Polynesians, in the Coromandel at these sites.
- Comparative studies on smaller catchments like the Kuaotunu with larger fluvial systems that have been affected by mining to deduce how the differences in natural ‘capping ’of the sediment impacts the movement of contaminated chemicals in the system. The preliminary results from this study suggest the natural capping of clean sediment reduced reworking in the smaller Kuaotunu Catchment, reducing further contamination.
- The use of geochemistry and Particle Size Analysis methodologies on future disturbance studies in New Zealand to further validate this methodology in deducing human disturbance at the site as it has been shown to be a useful method and proxy in this study and many other international projects. Furthermore in New Zealand they are particularly applicable due to the increased sedimentation observed from

deforestation of the hill country and the volcanic environment meaning changes in geochemistry can not only tell us about human induced changes but natural ones from volcanic activity so we can better understand the history of the environment and what changes it has undergone.

References

Adams, C. J. D., Wodzicki, A., & Weissberg, B. G. (1974). K-Ar dating of hydrothermal alteration at the Tui mine, Te Aroha, New Zealand. *New Zealand journal of science*, *17*, 193-199.

Adams, C. J., Graham, I. J., Seward, D., Skinner, D. N. B., Adams, C. J., Skinner, D. N. B., & Moore, P. R. (1994). Geochronological and geochemical evolution of late Cenozoic volcanism in the Coromandel Peninsula, New Zealand. *New Zealand journal of geology and geophysics*, *37*(3), 359-379.

Ahmed, A. A., & Ismail, U. H. A. E. (2008). Sediment in the Nile River system.*Consultancy Study requested by UNESCO*.

Ahyong, S. T. (2011). New Zealand Coastal Marine Invertebrates. *New Zealand Journal of Marine and Freshwater Research*, *45*(1), 161-163.

Alba-Sánchez, F., López-Sáez, J. A., Nieto-Lugilde, D., & Svenning, J. C. (2015). Long-term climate forcings to assess vulnerability in North Africa dry argan woodlands. *Applied Vegetation Science*, *18*(2), 283-296.

Alloway, B. V., Lowe, D. J., Barrell, D. J., Newnham, R. M., Almond, P. C., Augustinus, P. C., Bertler, N.A.N., Carter, L., Litchfield, N.J., McGlone, M.S., Shulmeister, J., Vandergoes, M.J. & Williams, P. W. (2007). Towards a climate event stratigraphy for New Zealand over the past 30 000 years (NZ-INTIMATE project). *Journal of Quaternary Science*, *22*(1), 9-35.

Ambers, R.K.R., (2001). Using the sediment record in a western Oregon flood-control reservoir to assess the influence of storm history and logging on sediment yield. *Journal of Hydrology* 244(3), 181–200.

Anderson, A. (1989). Mechanics of overkill in the extinction of New Zealand moas. *Journal of Archaeological Science*, *16*(2), 137-151.

Anderson, A. (2003). Initial human dispersal in Remote Oceania: pattern and explanation. *Pacific archaeology: assessments and prospects*, *15*, 71-84.

Atkins, C. B., & Dickinson, W. W. (2007). Landscape modification by meltwater channels at margins of cold-based glaciers, Dry Valleys, Antarctica. *Boreas*,*36*(1), 47-55.

Augustinus, P., D'Costa, D., Deng, Y., Hagg, J. & Shane, P. (2011). A multi-proxy record of changing environments from ca. 30 000 to 9000 cal. a BP: Onepoto maar palaeolake, Auckland, New Zealand. *Journal of Quaternary Science, 26*(4), 389-401.

Batalla, R.J. & Martin-Vide, J.P. (2001). Thresholds of particle entrainment in a poorly sorted sandy gravel-bed river. *Catena,* 44, 223-243.

Bathurst, J.C., Carling, P.A., Reid, I., Walling, D.E. & Webb, B. (1997). Sediment erosion, transport and deposition. In: Thorne, C.R., Hey, R.D. & Newson, M.D. (eds). *Applied Fluvial Geomorphology for River Engineering and Management,* Wiley, 95-135.

Bayliss-Smith, T., Hviding, E., & Whitmore, T. (2003). Rainforest composition and histories of human disturbance in Solomon Islands. *Ambio*, 346-352.

Behre, K. E. (1988). *The role of man in European vegetation history* (pp. 633-672). Springer Netherlands.

Berryman, K. (1988). Tectonic geomorphology at a plate boundary: a transect across Hawke Bay, New Zealand. *Geomorphology*, *69*, 69-86.

Beveridge, A.E. (1973). Regeneration of podocarps in a central North Island forest. *New Zealand Journal of Forestry, 18*, 23-35.

Black, P. M., & Skinner, D. N. B. (1979). The major oxide geochemistry of upper Tertiary Coromandel Group (andesites and dacites), northern Hauraki Volcanic Region, New Zealand. In: *Australia and New Zealand Association for the Advancement of Science Congress, abstracts I* (Vol. 182).

Bradshaw, B.E. (1991). *Nearshore and inner shelf sedimentation on the east Coromandel Coast, New Zealand* (Unpublished PhD thesis). University of Waikato, Hamilton, New Zealand.

Brathwaite, R. L., Christie, A. B., & Skinner, D. N. B. (1989). The Hauraki Goldfield-regional setting, mineralisation and recent exploration. *Mineral deposits of New Zealand*, *13*, 45-55.

Bridge, J.S. (2002). *Rivers and Floodplains: Forms, Processes, and Sedimentary Record* . Malden, MA: Blackwell.

Brierley, G.J., Fryirs, K.A. (2005). *Geomorphology and River Management: Applications of the River Styles Framework*. Blackwell Publishing, Oxford, UK.

Brown, A., Toms, P., Carey, C., & Rhodes, E. (2013). Geomorphology of the Anthropocene: time-transgressive discontinuities of human-induced alluviation. *Anthropocene*, *1*, 3-13.

Burge, L. M., & Smith, D. G. (1999). Confined meandering river eddy accretions: sedimentology, channel geometry and depositional processes.*Fluvial Sedimentology VI:(Special Publication 28 of the IAS)*, *53*, 113.

Burrows, C. J. (1965). Some discontinuous distributions of plants within New Zealand and their ecological significance II: Disjunctions between Otago- Southland and Nelson-Marlborough and related distribution patterns. *Tuatara, 13,* 9-29.

Bussell, M. R. (1988). Mid and late Holocene pollen diagrams and Polynesian deforestation, Wanganui district, New Zealand. *New Zealand journal of botany*,*26*(3), 431-451.

Byrami, M., Ogden, J., Horrocks, M., Deng, Y., Shane, P., & Palmer, J. (2002). A palynological study of Polynesian and European effects on vegetation in Coromandel, New Zealand, showing the variability between four records from a single swamp. *Journal of the Royal Society of New Zealand*, *32*(3), 507-531.

Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., & Smedley, P. (Eds.). (2013). *Essentials of medical geology* (p. 820). Springer.

Chagué-Goff, C., Nichol, S. L., Jenkinson, A. V., & Heijnis, H. (2000). Signatures of natural catastrophic events and anthropogenic impact in an estuarine environment, New Zealand. *Marine Geology*, *167*(3), 285-301.

Church, M. (1992). Channel Morphology and Topology. In*: The Rivers Handbook*, Calow, C. & Petts, G. (eds). Blackwell, Oxford, United Kingdom. (126-143).

Craw, D., & Chappell, D. A. (2000). Metal redistribution in historic mine wastes, Coromandel Peninsula, New Zealand. *New Zealand Journal of Geology and Geophysics*, *43*(2), 187-198.

Crecelius, E. A., Bothner, M. H., & Carpenter, R. (1975). Geochemistries of arsenic, antimony, mercury, and related elements in sediments of Puget Sound. *Environmental Science & Technology*, *9*(4), 325-333.

Cromack, K., Swanson, F. J., & Grier, C. C. (1978). A comparison of harvesting methods and their impact on soils and environment in the Pacific Northwest. In: *Forest soils and land use. Proceedings, 5th North American forest soils conference.* CT Youngberg (eds.). Colorado State University Press, Fort Collins, Colo (449-476).

Croudace, I. W., Rindby, A., & Rothwell, R. G. (2006). ITRAX: description and evaluation of a new multi-function X-ray core scanner. *Special publication-geological society of London*, *267*, 51.

Czymzik, M., Dulski, P., Plessen, B., von Grafenstein, U., Naumann, R., & Brauer, A. (2010). A 450 year record of spring-summer flood layers in annually laminated sediments from Lake Ammersee (southern Germany). *Water Resources Research*, *46*(11).

Davidson, J. (1987). *The Prehistory of New Zealand*. Longman Paul: New Zealand.

Davies, S.M., Abbott, P.M., Pearce, N.J.G., Wastegård, S., Blockley, S.P.E. (2012). Integrating the INTIMATE records using tephrochronology: rising to the challenge. *Quaternary Science Reviews, 36*, 11–27.

De Lange, P. J., & Lowe, D. J. (1990). History of vertical displacement of Kerepehi Fault at Kopouatai bog, Hauraki Lowlands, New Zealand, since c. 10 700 years ago. *New Zealand Journal of Geology and Geophysics*, *33*(2), 277-283.

DeRose, R. C., Trustrum, N. A., & Blaschke, P. M. (1993). Post-deforestation soil loss from steepland hillslopes in Taranaki, New Zealand. *Earth surface processes and landforms*, *18*(2), 131-144.

Dhivert, E., Grosbois, C., Rodrigues, S., & Desmet, M. (2015). Influence of fluvial environments on sediment archiving processes and temporal pollutant dynamics (Upper Loire River, France). *Science of the Total Environment*, *505*, 121-136.

Dixit, A. S., R. I. Hall, P. R. Leavitt, R. Quinlan & J. P. Smol. (2000). Effects of sequential depositional basins on lake response to urban and agricultural pollution: A palaeoecological analysis of the Qu'Appelle Valley, Saskatchewan, Canada. *Freshwater Biology. 43,* 319–337.

Downey, J. F. (2002). *Gold-mines of the Hauraki District, New Zealand*. Cadsonbury Publications.

Dunbar, G. B., McLea, B., & Goff, J. R. (1997). Holocene pollen stratigraphy and sedimentation, Wellington Harbour, New Zealand. *New Zealand journal of geology and geophysics, 40*(3), 325-333.

Eisma, D. (1986). Flocculation and de-flocculation of suspended matter in estuaries. *Netherlands Journal of Sea Research*, *20*(2), 183-199.

Elliot, M. B., Striewski, B., Flenley, J. R., & Sutton, D. G. (1995). Palynological and sedimentological evidence for a radiocarbon chronology of environmental change and Polynesian deforestation from Lake Taumatawhana, Northland, New Zealand. *Radiocarbon,* 37, 899-916.

Elliot, M. B., Striewski, B., Flenley, J. R., Kirkman, J. H., & Sutton, D. G. (1997). A 4300 year palynological and sedimentological record of environmental change and human impact from Wharau Road Swamp, Northland, New Zealand. *Journal of the Royal Society of New Zealand, 27*(4), 401-418.

Elliot, M.B., Flenley, J.R., Sutton, D.G. (1998). A late Holocene pollen record of deforestation and environmental change from the Lake Tauanui catchment, Northland, New Zealand. *Journal of Paleolimnology, 19*, 23–32.

Ellis, J., Nicholls, P., Craggs, R., Hofstra, D., & Hewitt, J. (2004). Effects of terrigenous sedimentation on mangrove physiology and associated macrobenthic communities. *Marine Ecology Progress Series, 270,* 71-82.

Ene, A., Bosneaga, A., & Georgescu, L. (2010). Determination of heavy metals in soils using XRF technique. *Romanian Journal of Physics, 55*(7-8), 815.

Escobar, J., Whitmore, T. J., Kamenov, G. D., & Riedinger-Whitmore, M. A. (2013). Isotope record of anthropogenic lead pollution in lake sediments of Florida, USA. *Journal of paleolimnology*, *49*(2), 237-252.

Esker, D., Sheridan, R. E., Ashley, G. M., Waldner, J. S., & Hall, D. W. (1996). Synthetic seismograms from vibracores: a case study in correlating the late Quaternary seismic stratigraphy of the New Jersey inner continental shelf. *Journal of Sedimentary Research*, *66*(6).

Ferguson, W., Flatman, F.R., Mitchelson, E., & Vickerman, C.R. (1910). *Waihou and Ohinemuri Rivers*. Wellington, NZ: Government Printer.

Fleming, C. A. (1979). *The geological history of New Zealand and its life*. Auckland University Press.

Foley, S.F., Gronenborn, D., Andreae, M.O., Kadereit, J.W., Esper, J., Scholz, D., Pöschl, U., Jacob, D.E., Schöne, B.R., Schreg, R., Vött, A., Jordan, D., Lelieveld, J.,Weller, C.G., Alt, K.W., Gaudzinski-Windheuser, S., Bruhn, K.-C., Tost, H., Sirocko, F. and Cutzen, P.J. (2013). The Palaeoanthropocene – the beginnings of anthropogenic environmental change. *Anthropocene*, 3, 83–88.

Fox, E.G. (2011). *Lake Waitawa Palynology Report*, (Unpublished report). Massey University, Palmerston North, New Zealand.

Franklin, J., Wiser, S. K., Drake, D. R., Burrows, L. E., & Sykes, W. R. (2006). Environment, disturbance history and rain forest composition across the islands of Tonga, Western Polynesia. *Journal of Vegetation Science*, *17*(2), 233-244.

Fuller, I.C., Macklin, M.G. & Richardson, J.M. (2015). The Geography of the Anthropocene in New Zealand: Differential River Catchment Response to Human Impact. *Geographical Research, 53 (*3), 255-269.

Gabites, Porter & Partners (1984). *Thames Valley United Council Regional Mining Study – Stage 1.* (Volume III). Thames, New Zealand: Thames-Coromandel District Council.

Gates, S. (2013). *The palynology of two Whangarei Craters, Northland, New Zealand*, (Unpublished Masters dissertation). Massey University, Palmerston North, New Zealand.

Gee, G. W., & Or, D. (2002). 2.4 Particle-size analysis. *Methods of soil analysis. Part 4*(598), 255-293.

Gilbert, R., & Glew, J. (1985). A Portable Percussion Coring Device for Lacustrine and Marine Sediments: RESEARCH METHOD PAPER. *Journal of Sedimentary Research*, *55*(4).

Glade, T. (1998). Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. *Environmental Geology*, *35*(2-3), 160-174.

Glade, T. (2003). Landslide occurrence as a response to land use change: a review of evidence from New Zealand. *Catena*, *51*(3), 297-314.

Glew, J. R., Smol, J. P., & Last, W. M. (2001). Sediment core collection and extrusion. In: *Tracking environmental change using lake sediments*, 73-105. Springer: Netherlands.

Goff, J. R. (1997). A chronology of natural and anthropogenic influences on coastal sedimentation, New Zealand. *Marine geology*, *138*(1), 105-117.

Gomez, B., Carter, L., Trustrum, N.A., Palmer, A.S., Roberts, A.P. (2004). El Nino-Southern Oscillation signal associated with middle Holocene climate change in intercorrelated terrestrial and marine sediment cores, North Island, New Zealand. *Geology, 32*(8), 653-656.

Gomez, B., Eden, D.N., Peacock, D.H., Pinkney, E.J. (1998). Floodplain construction by recent, rapid vertical accretion: Waipaoa River, New Zealand. *Earth Surface Processes and Landforms, 32*, 405– 413.

Gregory, K.J. (2006). The human role in changing river channels. *Geomorphology, 79*, 172 191.

Halverson, F., & Panzer, H. P. (1980). Flocculating agents. *Kirk-Othmer Encyclopedia of Chemical Technology*, *10*, 489-52

Hassan, M. A., Church, M., Lisle, T. E., Brardinoni, F., Benda, L., & Grant, G. E. (2005). Sediment Transport and Channel Morphology of Small, Forested Streams. *Journal of the American Water Resources Association (JAWRA), 41*(4), 853-876.
Bilby, R.E. (1981). Role of Organic Debris Dams in Regulating the Export of Dissolved and Particulate Matter from Forested Watershed. *Ecology ,62*, 1234-1243.

Hayward, B. W. (1978). *Kauaeranga Kauri: a pictorial history of the kauri timber industry in the Kauaeranga Valley, Thames*. Lodestar Press: New Zealand.

Healy, T. (2002). Muddy coasts of mid-latitude oceanic islands on an active plate margin—New Zealand. *Muddy coasts of the world: processes, deposits and function. Elsevier, Amsterdam*, 347-374.

Healy, T.R., Dell, P.M., & Willoughby, A.J. (1981). C*oromandel coastal survey* v*olume 1 basic survey data*. Hauraki Catchment Board. Report No. 114, 233p.

Heritage New Zealand (2009). *Days of gold* [Brochure]. New Zealand: Robinson, I.D.

Hogan, D. L., Bird, S. A., & Hassan, M. A. (1998). Spatial and temporal evolution of small coastal gravel-bed streams: influence of forest management on channel morphology and fish habitats. *Gravel-bed Rivers in the Environment*, 365-392.

Hogg, A. G., Higham, T. F., Lowe, D. J., Palmer, J. G., Reimer, P. J., & Newnham, R. M. (2003). A wiggle-match date for Polynesian settlement of New Zealand. *Antiquity, 77*(295), 116-125.

Holbrook, J., Scott, R. W., & Oboh-Ikuenobe, F. E. (2006). Base-level buffers and buttresses: a model for upstream versus downstream control on fluvial geometry and architecture within sequences. *Journal of Sedimentary Research*,*76*(1), 162-174.

Holdaway, R. N. (1999). A spatio-temporal model for the invasion of the New Zealand archipelago by the Pacific rat Rattus exulans. *Journal of the Royal Society of New Zealand*, *29*(2), 91-105.

Holdaway, R.N. (1996). Arrival of rats in New Zealand. *Nature, 384*,225–226.

Holt, K. A., Wallace, R. C., Neall, V. E., Kohn, B. P., & Lowe, D. J. (2010). Quaternary tephra marker beds and their potential for palaeoenvironmental reconstruction on Chatham Island, east of New Zealand, southwest Pacific Ocean. *Journal of Quaternary Science*, *25*(7), 1169-1178.

Hooke, J. (2003). Coarse sediment connectivity in river channel systems: a conceptual framework and methodology. *Geomorphology*, *56*(1), 79-94.

HORIBA. (2015). *Laser Scattering Particle Size Distribution Analyzer*: *partica LA-950V2* [Brochure]. Retrieved from: http://www.horiba.com/fileadmin/uploads/Scientific/Documents/PSA/LA950_V2_bro.pdf

Horrocks, M., Deng, Y., Ogden, J., & Sutton, D. G. (2000). A reconstruction of the history of a Holocene sand dune on Great Barrier Island, northern New Zealand, using pollen and phytolith analyses. *Journal of Biogeography, 27*(6), 1269-1277.

Horrocks, M., Nichol, S. L., D'Costa, D. M., Augustinus, P., Jacobi, T., Shane, P. A., & Middleton, A. (2007). A Late Quaternary record of natural change and human impact from Rangihoua Bay, Bay of Islands, northern New Zealand. .*Journal of Coastal Research*, 592-604.

Hudson-Edwards, K., Macklin, M., & Taylor, M. (1997). Historic metal mining inputs to Tees river sediment. *Science of the total Environment*, *194*, 437-445.

Hume, T.M. & Dahm, J. (1991). *An investigation of the effects of Polynesian and European land use on sedimentation in Coromandel estuaries.* Department of Conservation Consultancy Report, No. 7106:3, 47p.

Imperato, D. P. (1987). A Modification of the Vibracoring Technique for Sandy Sediment: RESEARCH METHOD PAPER. *Journal of Sedimentary Research*,*57*(4),788-789

Jones, R. T., Cook, C. G., Zhang, E., Langdon, P. G., Jordan, J., & Turney, C. (2012). Holocene environmental change at Lake Shudu, Yunnan Province, southwestern China. *Hydrobiologia*, *693*(1), 223-235.

Joosten, H., & de Klerk, P. (2007). In search of finiteness: the limits of fine-resolution palynology of Sphagnum peat. *The Holocene, 17*(7), 1023-1031.

Kennett, D., Anderson, A., Prebble, M., Conte, E., & Southon, J. (2006). Prehistoric human impacts on Rapa, French Polynesia. antiquity, 80(308), 340-354.

Kershaw, A. P., & Strickland, K. M. (1988). A Holocene pollen diagram from Northland, New Zealand. *New Zealand journal of botany*, *26*(1), 145-152.

Kirch, P. V. (1996). Late Holocene human-induced modifications to a central Polynesian island ecosystem. *Proceedings of the National Academy of Sciences,* 93(11), 5296-5300.

Kirch, P. V., & Green, R. C. (2001). *Hawaiki, ancestral Polynesia: an essay in historical anthropology.* Cambridge University Press.

Kirch, P.V. (2000). *On the Road of the Winds: An Archaeological History of the Pacific Islands Before European Contact*. University of California Press: Berkeley.

Knox, J. C. (2000). Sensitivity of modern and Holocene floods to climate change. *Quaternary Science Reviews*, *19*(1), 439-457.

Knox, J. C. (2001). Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *Catena*, *42*(2), 193-224.

Knox, J. C. (2006). Floodplain sedimentation in the Upper Mississippi Valley: Natural versus human accelerated. *Geomorphology*, *79*(3), 286-310.

Kohn, B. P., & Glasby, G. P. (1978). Tephra distribution and sedimentation rates m the Bay of Plenty, New Zealand. *New Zealand journal of geology and geophysics*, *21*(1), 49-70.

Kondos, P. D., Deschenes, G., & Morrison, R. M. (1995). Process optimization studies in gold cyanidation. *Hydrometallurgy*, *39*(1), 235-250.

Last, W. M., & Smol, J. P. (2001). *Tracking environmental change using lake sediments. Vol. 1, Basin analysis, coring, and chronological techniques*. Kluwer Academic Publishers.

Lee, K. (1989). *The impact of hushing on a channel and floodplain morphology: a case study of the Hudeshope Beck, upper Teesdale* (Doctoral dissertation, BSc Thesis), University of Newcastle upon Tyne.

Leopold, L. B. (1973). River channel change with time: an example address as Retiring President of The Geological Society of America, Minneapolis, Minnesota, November 1972. *Geological Society of America Bulletin*, *84*(6), 1845-1860.

Li, X., Flenley, J. R., & Rapson, G. L. (2014). Untangling the causes of vegetation change in a 5,300 year pollen record at Tiniroto Lakes, Gisborne, New Zealand. *Vegetation history and archaeobotany*, *23*(2), 87-96.

Lipman, P. W., & Mullineaux, D. R. (Eds.). (1981). *The 1980 eruptions of Mount St. Helens, Washington* (No. 1250). US Dept. of the Interior, US Geological Survey.

López, P., López-Sáez, J. A., Chernykh, E. N., & Tarasov, P. (2003). Late Holocene vegetation history and human activity shown by pollen analysis of Novienki peat bog (Kargaly region, Orenburg Oblast, Russia). *Vegetation history and archaeobotany*,*12*(1), 75-82

Lovelock, C. E., Feller, I. C., Ellis, J., Schwarz, A. M., Hancock, N., Nichols, P., & Sorrell, B. (2007). Mangrove growth in New Zealand estuaries: the role of nutrient enrichment at sites with contrasting rates of sedimentation. *Oecologia, 153*(3), 633-641.

Lowe, D. J., Blaauw, M., Hogg, A. G., & Newnham, R. M. (2013). Ages of 24 widespread tephras erupted since 30,000 years ago in New Zealand, with re-evaluation of the timing and palaeoclimatic implications of the Lateglacial cool episode recorded at Kaipo bog. *Quaternary Science Reviews*, *74*, 170-194.

Lowe, D. J., Shane, P. A., Alloway, B. V., & Newnham, R. M. (2008). Fingerprints and age models for widespread New Zealand tephra marker beds erupted since 30,000 years ago: a framework for NZ-INTIMATE. *Quaternary Science Reviews*, *27*(1), 95-126.

Lowe, D. J., Hogg, A. G., Green, J. D., & Boubee, J. A. T. (1980). Stratigraphy and chronology of late Quaternary tephras in Lake Maratoto, Hamilton, New Zealand. *New Zealand journal of geology and geophysics, 23(*4), 481-485.

LRIS Portal. (2015). *Soil Map of Coromandel*. Retrieved from https://lris.scinfo.org.nz/layer/159-soil-map-of-coromandel/

LRIS Portal. (2015). *Soil Survey of Ohinemuri County.* Retrieved from https://lris.scinfo.org.nz/layer/154-soil-survey-of-ohinemuri-county/

MacDonald-Creevey, A. M. (2011). *Late Holocene environmental record and geological history of the Lake Colenso area, north-western Ruahine Range, New Zealand: a thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Quaternary Science, Soil and Earth Sciences, Institute of Natural Resources, Massey University, Palmerston North, New Zealand* (Doctoral dissertation)

Macklin, M. G., & Newson, M. (1992). Metal pollution of soils and sediment: a geographical perspective. *Managing the human impact on the natural environment: patterns and processes.*, 172-195.

Macklin, M. G., Brewer, P. A., Hudson-Edwards, K. A., Bird, G., Coulthard, T. J., Dennis, I. A., Lechler, P.J., Miller, J.R. & Turner, J. N. (2006). A geomorphological approach to the management of rivers contaminated by metal mining. *Geomorphology*, *79*(3), 423-447.

Macklin, M. G., Hudson-Edwards, K. A., & Dawson, E. J. (1997). The significance of pollution from historic metal mining in the Pennine orefields on river sediment contaminant fluxes to the North Sea. *Science of the total Environment*, *194*, 391-397.

Manju, P., Nair Akhil, P. S., & Sujatha, C. H. (2014). Toxic metal distribution in the core sediment of Cochin Estuarine System (CES). International Journal of Environmental Research, 8(1), 133-138.

Marquer, L., Gaillard, M. J., Sugita, S., Trondman, A. K., Mazier, F., Nielsen, A. B., Fyfe, R.M., Odgaard, B.V., Alenius, T., Birks, H.J.B., Bjune, A.E., Christiansen, J., Dodson, J., Edwards, K.J., Giesecke, T., Herzchuh, U., Kangur, M., Lorenz, S., Poska, A., Schult, M., Seppa, H. (2014). Holocene changes in vegetation composition in northern Europe: why quantitative pollen-based vegetation reconstructions matter. *Quaternary Science Reviews*, *90*, 199-216.

McAndrews, J. H. (1988). Human disturbance of North American forests and grasslands: the fossil pollen record. In: *Vegetation history* (pp. 673-697). Springer Netherlands.

McConchie, J. A. (1980). Implication of landslide activity for urban drainage.*New Zealand Journal of Hydrology*, *19*(1), 27-34.

McConchie, J.A., (1977). *The geomorphological and hydrological response to the 20 December 1976 storm, Stokes Valley*. (Unpublished BSc (Hons) thesis), Victoria University of Wellington, New Zealand.

McGlone, M. S. (1978). Forest destruction by early Polynesians, Lake Poukawa, Hawkes Bay, New Zealand. *Journal of the Royal Society of New Zealand, 8*(3), 275-281.

McGlone, M. S. (1983). Polynesian deforestation of New Zealand: a preliminary synthesis. *Archaeology in Oceania, 18,* 11-25.

McGlone, M. S. (1985) Plant biogeography and the late Cenozoic history of New Zealand. *New Zealand journal of botany, 23*. 723-749.

McGlone, M. S., Neall, V. E., & Clarkson, B. D. (1988). The effect of recent volcanic events and climatic changes on the vegetation of Mt Egmont (Mt Taranaki), New Zealand. *New Zealand journal of botany, 26*(1), 123-144.

McGlone, M. S. (1989). The Polynesian settlement of New Zealand in relation to environmental and biotic changes*. New Zealand Journal of Ecology*, 115-129.

McGlone, M. S., & Basher, L. (2012). Holocene vegetation change at treeline, Cropp Valley, Southern Alps, New Zealand. *Peopled landscapes: Archaelogcial and biogeographic approaches to landscapes. Terra Australis*, *34*, 343-358.

McGlone, M. S., & Wilmshurst, J. M. (1999). Dating initial Maori environmental impact in New Zealand. *Quaternary International, 59*(1), 5-16.

McGlone, M. S., Topping, W. W. (1977). Aranuian (postglacial) pollen diagrams from the Tongariro region, North Island, New Zealand. *New Zealand journal of botany, 15*, 749-760.

McGlone, M.S. & Wilson, H.D. (1996). Holocene vegetation and climate of Stewart Island, New Zealand. *New Zealand Journal of Botany, 34,* 369-388.

McGlone, M.S., Mark, A.F., Bell, D. (1995). Late Pleistocene and Holocene vegetation history, Central Otago, South Island, New Zealand. *Journal of the Royal Society of New Zealand, 25*(1), 1-22.

McGlone, M.S., Salinger, J.M., Moar, N.T., (1993). Palaeovegetation studies of New Zealand's climate since the Last Glacial Maximum. In: *Global Cliamtes Since the Last Glacial Maximum.* University of Minnesota Press, Minneapolis, London. 294-317.

McWethy, D. B., Whitlock, C., Wilmshurst, J. M., McGlone, M. S., Fromont, M., Li, X., Dieffenbacher-Krall, A., Hobbs, W.O., Fritz, S.C. & Cook, E. R. (2010). Rapid landscape transformation in South Island, New Zealand, following initial Polynesian settlement. *Proceedings of the National Academy of Sciences*, *107*(50), 21343-21348.

McWethy, D. B., Whitlock, C., Wilmshurst, J. M., McGlone, M. S., & Li, X. (2009). Rapid deforestation of South Island, New Zealand, by early Polynesian fires. *The Holocene*, *19*(6), 883-897.

Mead, S. & Moores, A. (2005). *Estuary sedimentation: a review of estuarine sedimentation in the Waikato region* (Environment Waikato Technical Report Series 2005/13). Hamilton, New Zealand: Environment Waikato.

Metservice. (2014). *Coromandel Weather.* Retrieved from http://www.metservice.com/rural/coromandel

Mildenhall, D. C. (1979). Holocene pollen diagrams from Pauatahanui Inlet, Porirua, New Zealand. *New Zealand journal of geology and geophysics, 22*(5), 585-591.

Mildenhall, D. C., & Orpin, A. R. (2010). Terrestrial palynology from marine cores as an indicator of environmental change for the Waipaoa Sedimentary System and north-eastern New Zealand. *Marine Geology*, *270*(1), 227-234.

Molloy, B.P.J., Burrows, C.J., Cox, J.E., Johnson, J.A. & Wardle, P. (1963). Distribution of subfossil forest remains in eastern South Island, New Zealand. *New Zealand Journal of Botany, 1,* 68-77.

Moore, P. & Ritchie, N. (1996). *Coromandel Gold: A guide to the historic Goldfields of the Coromandel Peninsula*. Dunmore Press, New Zealand.

Moriwaki, H., Suzuki, T., Murata, M., Ikehara, M., Machida, H., Oba, T., Lowe, D.J. (2012). Sakurajima-Satsuma (Sz-S) and Noike-Yumugi (N-Ym) tephras: new tephrochronological marker beds for the last deglaciation, southern Kyushu, Japan. *Quaternary International, 246,* 203–212.

Morra, M. J., Carter, M. M., Rember, W. C., & Kaste, J. M. (2015). Reconstructing the history of mining and remediation in the Coeur d'Alene, Idaho Mining District using lake sediments. *Chemosphere*, *134*, 319-327.

Naish, T. R. (1990). *Late Holocene mud sedimentation and diagenesis in the Firth of Thames: Bentonites in the making* (Doctoral dissertation, University of Waikato).

Nanson, G. C. (1986). Episodes of vertical accretion and catastrophic stripping: a model of disequilibrium flood-plain development. *Geological Society of America Bulletin*, *97*(12), 1467-1475.

Needham, S. (2003). *Golden Cross Mine, New Zealand: Closure and rehabilitation*.Neological Consulting NSW, Australia.

Nesje, A. (1992). A piston corer for lacustrine and marine sediments. *Arctic and Alpine Research*, 257-259.

Newmont. (2015). *The modern Martha Mine*. Retrieved from http://www.waihigold.co.nz/history/timeline/modern-martha/

Newnham, R. M., Lowe, D. J., & Wigley, G. N. A. (1995). Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand. *Journal of the Royal Society of New Zealand*, *25*(2), 283-300.

Newnham, R. M., Lowe, D. J., McGlone, M. S., Wilmshurst, J. M., & Higham, T. F. G. (1998). The Kaharoa Tephra as a critical datum for earliest human impact in northern New Zealand. *Journal of Archaeological Science*, *25*(6), 533-544.

Newnham, R., McGlone, M., Moar, N., Wilmshurst, J., & Vandergoes, M. (2013). The vegetation cover of New Zealand at the last glacial maximum.*Quaternary Science Reviews*, *74*, 202-214.

Newnham, R.M., Lowe, D.J., Giles, T., Alloway, B.V. (2007). Vegetation and climate of Auckland, New Zealand, since ca. 32000cal. yr ago: support for an extended LGM. *Journal of Quaternary Science, 22*(5), 517-534.

Newnham, R.M., Lowe, D.J., Williams, P.W. (1999). Quaternary environmental change in New Zealand: a review. *Progress in Physical Geography, 23*(4), 567-610.

Nichol, S. L., Augustinus, P. C., Gregory, M. R., Creese, R., & Horrocks, M. (2000). Geomorphic and sedimentary evidence of human impact on the New Zealand coastal landscape. *Physical geography*, *21*(2), 109-132.

Ogden, J.& Caithness, T. A. (1982): The history and present vegetation of the macrophyte swamp at Pukepuke Lagoon. *New Zealand Journal of Ecology, 5*,108-120.

Ogden, J., Basher, L. E. S., & McGlone, M. (1998). Fire, forest regeneration and links with early human habitation: evidence from New Zealand. *Annals of Botany*, 687-696.

Ogden, J., Deng, Y., Boswijk, G., & Sandiford, A. (2003). Vegetation changes since early Maori fires in Waipoua Forest, northern New Zealand. *Journal of archaeological science*, *30*(6), 753-767.

Owens, P. N., & Walling, D. E. (2002). Changes in sediment sources and floodplain deposition rates in the catchment of the River Tweed, Scotland, over the last 100 years: the impact of climate and land use change. *Earth Surface Processes and Landforms*, *27*(4), 403-423.

Page, M. J., & Trustrum, N. A. (1997). A late Holocene lake sediment record of the erosion response to land use change in a steepland catchment, New Zealand. *Zeitschrift fur Geomorphologie*, *41*(3), 369-392.

Page, M. J., Trustrum, N. A., & DeRose, R. C. (1994). A high resolution record of storm-induced erosion from lake sediments, New Zealand. *Journal of Paleolimnology*, *11*(3), 333-348.

Palmer, P. T., Jacobs, R., Baker, P. E., Ferguson, K., & Webber, S. (2009). Use of field-portable XRF analyzers for rapid screening of toxic elements in FDA-regulated products. *Journal of agricultural and food chemistry, 57*(7), 2605-2613.

Pang, L. (1995) Contamination of groundwater in the Te Aroha area by heavy metals from an abandoned mine. *Journal of Hydrology (New Zealand), 33,* 17-34.

Paul, R. W. (2001). *Mining frontiers of the Far West, 1848-1880*. University of New Mexico Press: USA.

Pawson, E., & Brooking, T. (Eds.). (2002). *Environmental Histories of New Zealand* (Vol. 342). Melbourne: Oxford University Press.

Pearson, L. K., Hendy, C. H., Hamilton, D. P., & Pickett, R. C. (2010). Natural and anthropogenic lead in sediments of the Rotorua lakes, New Zealand. *Earth and Planetary Science Letters*, *297*(3), 536-544.

Pickett, S.T.A., & P.S. White. (1985). *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, Inc. Orlando, Florida

Plangoen, P., Babel, M. S., Clemente, R. S., Shrestha, S., & Tripathi, N. K. (2013). Simulating the impact of future land use and climate change on soil erosion and deposition in the Mae Nam Nan sub-catchment, Thailand.*Sustainability*, *5*(8), 3244-3274.

Plater, A. J., Boyle, J. F., Mayers, C., Turner, S. D., & Stroud, R. W. (2006). Climate and human impact on lowland lake sedimentation in Central Coastal California: the record from c. 650 AD to the present. *Regional Environmental Change*, *6*(1-2), 71-85.

Radu, T., & Diamond, D. (2009). Comparison of soil pollution concentrations determined using AAS and portable XRF techniques. *Journal of Hazardous Materials*, *171*(1), 1168-1171.

Ralska-Jasiewiczowa, M., & van Geel, B. (1992). Early human disturbance of the natural environment recorded in annually laminated sediments of Lake Gosciaz, central Poland. *Vegetation History and Archaeobotany*, *1*(1), 33-42.

Ralston, D. K., Geyer, W. R., Traykovski, P. A., & Nidzieko, N. J. (2013). Effects of estuarine and fluvial processes on sediment transport over deltaic tidal flats. *Continental Shelf Research*, *60*, 40-57.

Razo, I., Carrizales, L., Castro, J., Díaz-Barriga, F., & Monroy, M. (2004). Arsenic and heavy metal pollution of soil, water and sediments in a semi-arid climate mining area in Mexico. *Water, Air, and Soil Pollution*, *152*(1-4), 129-152.

Reasoner, M. A. (1986). An inexpensive, lightweight percussion core sampling system. *Géographie physique et Quaternaire*, *40*(2), 217-219.

Reible, D., Lampert, D., Constant, D., Mutch Jr, R. D., & Zhu, Y. (2006). Active capping demonstration in the Anacostia River, Washington, DC. *Remediation Journal, 17*(1), 39-53.

Reid, L. M., & Page, M. J. (2003). Magnitude and frequency of landsliding in a large New Zealand catchment. *Geomorphology*, *49*(1), 71-88.

Richardson, J. M., Fuller, I. C., Holt, K. A., Litchfield, N. J., & Macklin, M. G. (2014). Rapid post-settlement floodplain accumulation in Northland, New Zealand. *Catena*, *113*, 292-305.

Richardson, J. M., Fuller, I. C., Macklin, M. G., Jones, A. F., Holt, K. A., Litchfield, N. J., & Bebbington, M. (2013). Holocene river behaviour in New Zealand: response to regional centennial-scale climate forcing. *Quaternary Science Reviews*, *69*, 8-27.

Ritter, D. F., Kinsey, W. F., & Kauffman, M. E. (1973). Overbank sedimentation in the Delaware River Valley during the last 6000 years. *Science*,*179*(4071), 374-375.

Roberts, R. G., & Church, M. (1986). The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia. *Canadian Journal of Forest Research, 16*(5), 1092-1106.

Ross, D.J., McQueen, D.J., & Kettles, H.A. (1994). Land rehabilitation under pasture on volcanic parent materials: changes in soil microbial biomass and C and N metabolism. *Australian Journal of Soil Research, 32*, 1321- 1327.

Rothwell, R. G., & Rack, F. R. (2006). New techniques in sediment core analysis: an introduction. *Geological Society, London, Special Publications*,*267*(1), 1-29.

Roulet, M., Lucotte, M., Canuel, R., Farella, N., Courcelles, M., Guimaraes, J. R., Mergler, D.& Amorim, M. (2000). Increase in mercury contamination recorded in lacustrine sediments following deforestation in the central Amazon. *Chemical Geology*, *165*(3), 243-266.

Rowan, J.S., S.J.A. Barnes, S.L. Hetherington & B. Lambers. (1995). Geomorphology and pollution: the environmental impacts of lead mining, Leadhills, Scotland. *Journal of geochemical Exploration,* 52(1-2), 7-65.

Rucker, J. B., & Snowden, J. O. (1990). Barrier island evolution and reworking by inlet migration along the Mississippi-Alabama Gulf Coast

Ruddiman, W. F., Kutzbach, J. E., & Vavrus, S. J. (2011). Can natural or anthropogenic explanations of late-Holocene CO2 and CH4 increases be falsified?. *The Holocene*, 0959683610387172.

Ruddiman, W.F. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climatic Change*, *61*, 261-293.

Rumsby, B. T., & Macklin, M. G. (1994). Channel and floodplain response to recent abrupt climate change: the Tyne Basin, Northern England. *Earth Surface Processes and Landforms*, *19*(6), 499-515.

Sabti, H., Hossain, M. M., Brooks, R. R., & Stewart, R. B. (2000). The current environmental impact of base-metal mining at the Tui Mine, Te Aroha, New Zealand. *Journal of the Royal Society of New Zealand*, *30*(2), 197-207.

Salinger, M. J.; Basher, R.E.; Fitzharris, B.B.; Hay, J.E.; Jones, P.D.; MacVeigh, J.P.; Schmidely-Leleu, I. (1995). Climate trends in the Southwest Pacific. *International Journal of Climatology, 15,*: 285–302.-

Salmon, H.M. (1963). *A History of Gold Mining in New Zealand*. Cadsonbury Publicaations, Christchurch.

Schumm, S. A., & Lichty, R. W. (1965). Time, space, and causality in geomorphology. *American Journal of Science*, *263*(2), 110-119.

Shennan, S. (2009). Evolutionary demography and the population history of the European early Neolithic. *Human Biology*, *81*(3), 339-355.

Simonneau, A., Doyen, E., Chapron, E., Millet, L., Vanniere, B., Di Giovanni, C., Arnaud, F. (2013). Holocene land-use evolution and associated soil erosion in the French Prealps inferred from Lake Paladru sediments and archaeological evidences. *Journal of Archaeological Science*, *40*(4), 1636-1645.

Simpson, S. L., Pryor, I. D., Mewburn, B. R., Batley, G. E., & Jolley, D. (2002). Considerations for capping metal-contaminated sediments in dynamic estuarine environments. *Environmental Science & Technology, 36*(17), 3772-3778.

Sims, D. B., & Francis, A. (2008). Mercury and cyanide used as indicators of sediment transport in ephemeral washes at the techatticup mine and mill site, nelson, Nevada (USA). *International Journal of Soil, Sediment and Water*, *1*(2), 4.

Skinner, D. N. B. (1986). Neogene volcanism of the Hauraki volcanic region.*Royal society of New Zealand bulletin*, *23*, 21-47.

Smith, N. D., & Rogers, J. (Eds.). (2009). *Fluvial Sedimentology VI (Special Publication 28 of the IAS)* (Vol. 26). John Wiley & Sons.

Smol, J.P. (2009). *Pollution in Lakes and Rivers: A Palaeoenvironmental Perspective* John Wiley & Sons: USA.

Spriggs, M. & Anderson, A. (1993). Late colonization of East Polynesia. *Antiquity, 67,*200–217.

Stanley, E. H., Luebke, M. A., Doyle, M. W., & Marshall, D. W. (2002). Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. *Journal of the North American Benthological Society*,*21*(1), 172-187.

Statistics New Zealand (2015). *2013 Census Quickstats about a place: Coromandel*. Retrieved from: http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-a-place.aspx?request_value=13634&parent_id=13632&tabname=

Stewart, E. M., Michelutti, N., Blais, J. M., Mallory, M. L., Douglas, M. S., & Smol, J. P. (2013). Contrasting the effects of climatic, nutrient, and oxygen dynamics on subfossil chironomid assemblages: a paleolimnological experiment from eutrophic High Arctic ponds. *Journal of paleolimnology, 49*(2), 205-219.

Storey, J. (1994). *"Gold's the thing?" A study of community conflict on the Coromandel.* (Working papers in Sociology No. 25). Auckland, New Zealand: The University of Auckland.

Striewski, B., Mayr, C., Flenley, J., Naumann, R., Turner, G., & Lücke, A. (2009). Multi-proxy evidence of late Holocene human-induced environmental changes at Lake Pupuke, Auckland (New Zealand). *Quaternary International*,*202*(1), 69-93.

Sutton, D. G. (1987). A paradigmatic shift in Polynesian prehistory: implications for New Zealand. *New Zealand Journal of Archaeology, 9*(135), 55.

Sutton, D. G., Flenley, J. R., Li, X., Todd, A., Butler, K., Summers, R., & Chester, P. I. (2008). The timing of the human discovery and colonization of New Zealand. *Quaternary International*, *184*(1), 109-121.

Swales, A., Bentley, S. J., Lovelock, C., & Bell, R. G. (2007, May). Sediment processes and mangrove-habitat expansion on a rapidly-prograding muddy coast, New Zealand. In: *Coastal Sediments* (Vol. 7, pp. 1441-1454).

Tapia, P. M., Fritz, S. C., Baker, P. A., Seltzer, G. O., & Dunbar, R. B. (2003). A Late Quaternary diatom record of tropical climatic history from Lake Titicaca (Peru and Bolivia). Palaeogeography, Palaeoclimatology, Palaeoecology, 194(1), 139-164.

Taschereau, C., & Fytas, K. (2000). Arsenic in mine tailings-the Chimo Mine case study. *International Journal of Surface Mining, Reclamation and Environment,* 14(4), 337-347.

Tomlinson, A.I. (1976). *Climate*. In: Ward, I. (eds), New Zealand Atlas. N.Z. Government Printer, Wellington, pp. 82-89.

Trustrum, N. A., & Page, M. J. (1992). The long term erosion history of Lake Tutira watershed: implications of sustainable land use management. In: *Proceedings of International Conference on Sustainable Land Management. Napier, New Zealand* (212-215).

Vandenberghe, J., de Moor, J.J.W., Spanjaard, G. (2012). Natural change and human impact in a present-day fluvial catchment: The Geul River, Southern Netherlands. *Geomorphology, 159-160*, 1-14.

Vandergoes, M.J., Fitzsimons, S.J., Newnham, R.M. (1997). Late glacial to Holocene vegetation and climate change in the eastern Takitimu Mountains, western Southland, New Zealand. *Journal of the Royal Society of New Zealand, 27*(1), 53-66.

Velásquez-López, P. C., Veiga, M. M., & Hall, K. (2010). Mercury balance in amalgamation in artisanal and small-scale gold mining: identifying strategies for reducing environmental pollution in Portovelo-Zaruma, Ecuador. *Journal of Cleaner Production, 18*(3), 226-232.

Waikato Regional Council. (2015). *Waikato Regional Plan - Water Allocation Maps* [Brochure]. New Zealand: Waikato Regional Council.

Ward, N. I., Brooks, R. R., & Roberts, E. (1977). Contamination of a pasture by a New Zealand base-metal mine. *New Zealand Journal of Science*.

Wardle, P. (1963) Evolution and distribution of the New Zealand flora, as affected by Quaternary climates. *New Zealand journal of botany, 1,* 3-17.

Waters, C.N., Zalasiewicz, J.A., Williams, M., Ellis, M.A. and Snelling, A.M. (2014). A Stratigraphical Basis for the Anthropocene. Geological Society, London, Special Publication, 395, 1–21.

Watt, A. S. (1940). Contributions to the ecology of bracken (Pteridium aquilinum). I. The rhizome. *New Phytologist*, *39*(4), 401-422.

Watton, G. (2006). The Flood of All Floods. *Ohinemuri Regional History Journal*, *50*(1). Retrieved from http://www.ohinemuri.org.nz/journal/50/flood_of_all_floods.htm

Webster, K. L., Ogston, A. S., & Nittrouer, C. A. (2013). Delivery, reworking and export of fine-grained sediment across the sandy Skagit River tidal flats. *Continental Shelf Research*, *60*, S58-S70.

Wei, M., Kun, L., Binghui, Z. H. E. N. G., Fu, W. A. N. G., Hong, W. A. N. G., Jianfen, L., & Yong, L. I. (2005). Modern sedimentation rates in the intertidal zone on the west coast of the Bohai Gulf, *海洋学报, 24*(3).

Weston, F.W. (1927). *Thames goldfields: a history from Pre-Proclamation times to 1927.* Thames Star; New Zealand.

Wilby, R. L., Dalgleish, H. Y., & Foster, I. D. L. (1997). The impact of weather patterns on historic and contemporary catchment sediment yields. *Earth Surface Processes and Landforms*, *22*(4), 353-363.

Williams, G. J., & McKee, T. J. (1974). Economic geology of New Zealand. *Australasian Institute of Mining and metallurgy*.

Williams, M. (2001). Arsenic in mine waters: an international study.*Environmental Geology*, *40*(3), 267-278.

Wilmshurst, J. M. (1997). The impact of human settlement on vegetation and soil stability in Hawke's Bay, New Zealand*. New Zealand Journal of Botany, 35*(1), 97-111.

Wilmshurst, J. M., Anderson, A. J., Higham, T. F., & Worthy, T. H. (2008). Dating the late prehistoric dispersal of Polynesians to New Zealand using the commensal Pacific rat. *Proceedings of the National Academy of Sciences*,*105*(22), 7676-7680.

Wilmshurst, J. M., Eden, D. N., & Froggatt, P. C. (1999). Late Holocene forest disturbance in Gisborne, New Zealand: a comparison of terrestrial and marine pollen records. *New Zealand Journal of Botany, 37*(3), 523-540.

Worthy, T. H. (1999). What was on the menu? Avian extinction in New Zealand.*New Zealand Journal of Archaeology*, *19*, 125-160.

Wriedt, T. (2012). Mie theory: a review. In: *The Mie Theory* (pp. 53-71). Springer: Berlin Heidelberg.

Xu, J. (2003). Sedimentation rates in the lower Yellow River over the past 2300 years as influenced by human activities and climate change. *Hydrological Processes, 17*(16), 3359-3371.

Xu, JX. (2004). Effect of human activities on overall trend of sedimentation in the lower Yellow River, China. *Environmental Management*, *33*(5), 637-653

Yim, W.W.S. (1976). Heavy Metals Accumulation in Estuarine Sediments in a Historic Mining of Cornwall. *Marine Pollution Bulletin*, 7(8), 147-150

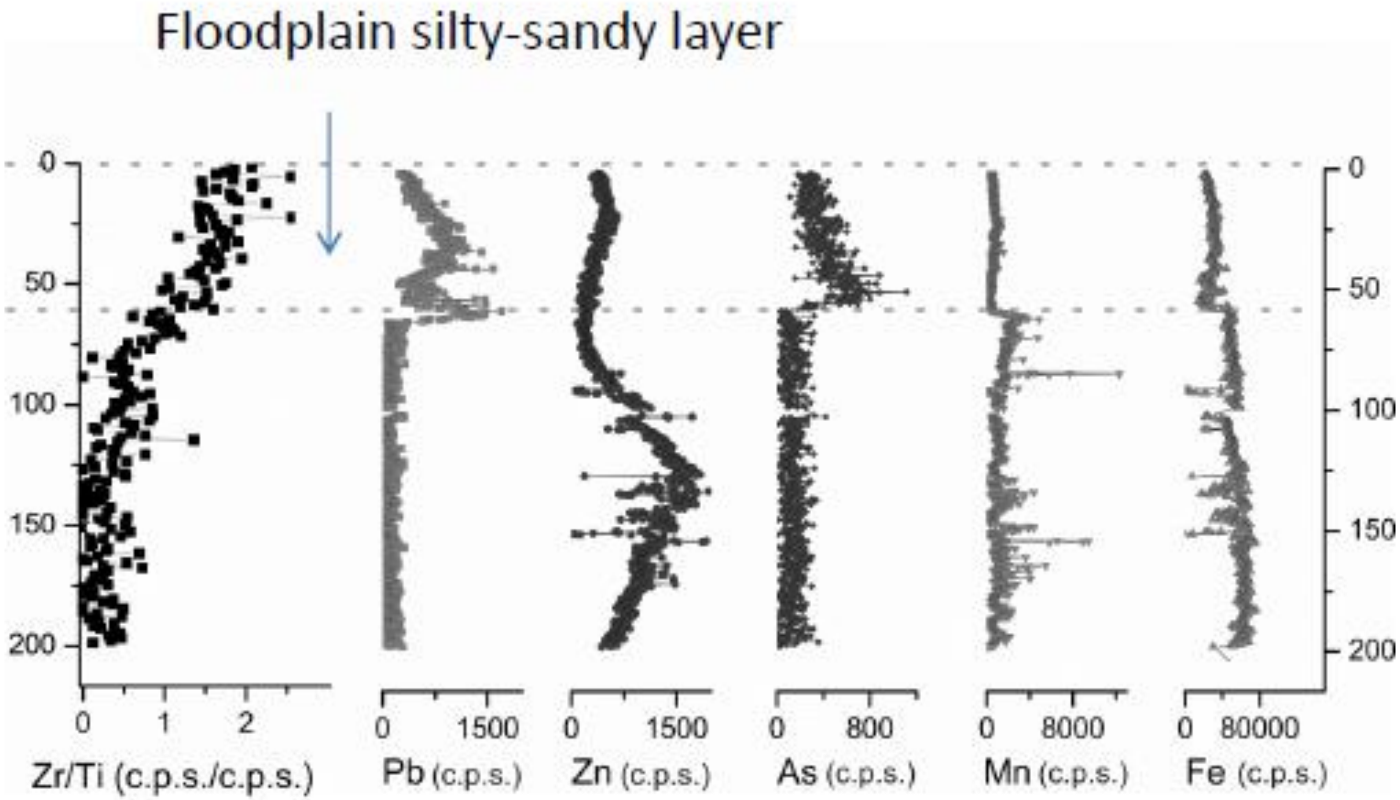
Young, B. M., & Harvey, E. L. (1996). A spatial analysis of the relationship between mangrove (Avicennia marinavar. australasica) physiognomy and sediment accretion in the Hauraki Plains, New Zealand. *Estuarine, Coastal and Shelf Science, 42*(2), 231-246.

Zabowski, D., Rygiewicz, P. T., & Skinner, M. F. (1996). Site disturbance effects on a clay soil under radiata pine. *Plant and soil*, *186*(2), 343-351.

Zolitschka, B., Mingram, J., Van Der Gaast, S., Jansen, J. F., & Naumann, R. (2001). Sediment logging techniques. In: *Tracking environmental change using lake sediments* (pp. 137-153). Springer Netherlands.

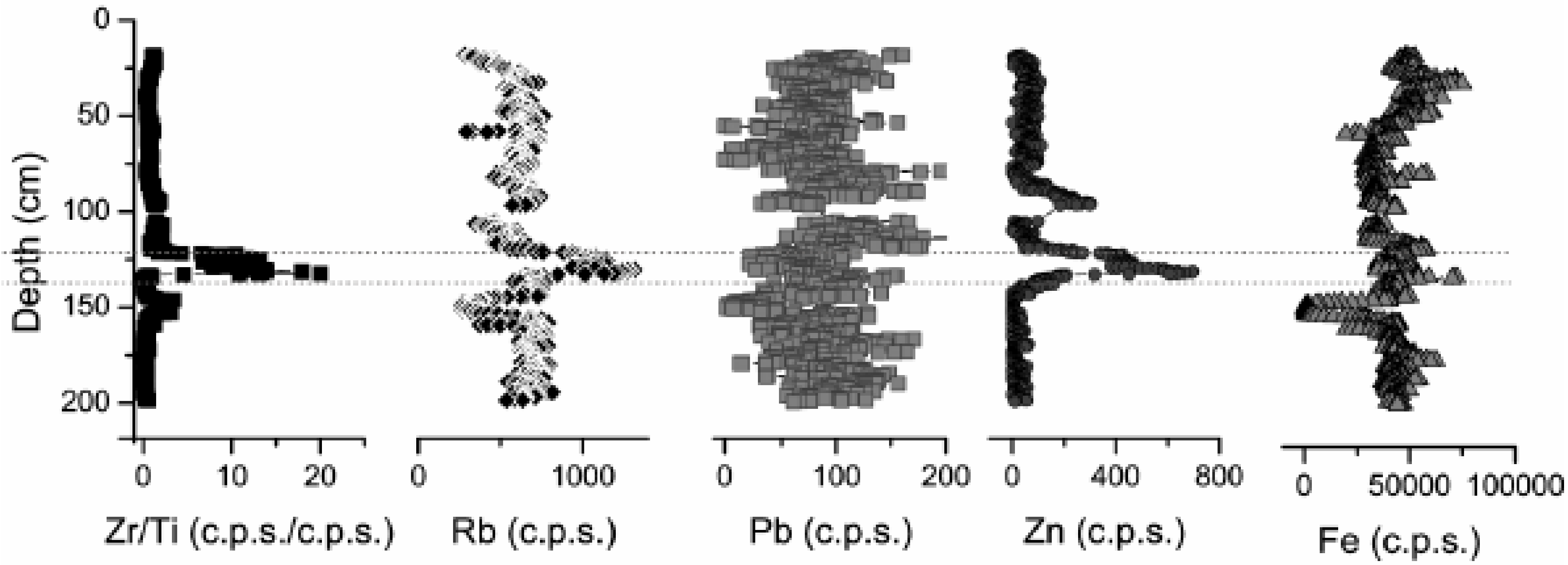
Appendices:

Appendix 5.1: XRF ITRAX results for Maori Road Core, with depth on y axis and measured amount of each chemical on the x axis. Similarly to the NITON results there is a clear change shown by the second dashed line. Above the second dashed line was the silty-sand layer



indicating change of the system.

Appendix 5.2: XRF ITRAX results for the Gerard Road cores. Similarly as the NITON results there is a clear peak in chemicals, coinciding with what has been interpreted as a tephra layer.



Appendix 453: Maori Road Core physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0 - 30	10YR 4/2	Sandy, rough, well sorted material; 70% sand 30% silt	fine roots extending down past this layer, piece of wood found in middle of core	appears to be top soil layer, sandy soil perhaps? Semi-distinct boundary layer, slight grading	top soil
30 - 300	10 YR 4/3 grading to 10 YR 4/4 at 190 mm, slightly mottled with flecks of lighter shade at 190mm	Rough sand, well sorted, more silt present than above, still grainy feeling but smoother, potentially clay; 60 % sand, 35% silt 5% clay	fine roots throughout, larger in size than above lengthways	Slowly grading to a lighter colour	Silty Sand
300 - 340	10 YR 4/4 more mottling, mixture of colour	Similar texture as above, sand still dominant but underlying silty/clay feeling; 50% sand	finer roots than above, thinner, more hair-like	Potentially bits of charcoal	Silty Sand
340 - 450	10 YR 4/6, lighter in colour, grading	Similar texture as above, sand still dominant but underlying silty/clay feeling; 50% sand	Thin, more hair-like roots	Potentially bits of charcoal; orange oxidised bits	Silty Sand
450 - 520	10 YR 4/6 orange flecks, very mottled with 10YR 7/3 for light bits within	Sand still dominant but clay/silty more evident than above; 45% sand	Miniscule roots, very few	Orange oxidised parts, pumice bits, charcoal?	Silty Sand
520-600	Mottled 10YR 4/6 and 10YR 5/6, clear orange layers at 520-530 and 554-562	Finer grained sandy feel, some small clumps; more silty feel 40% sand 35% silt 25% clay	Miniscule roots, very few	Orange oxidised parts, pumice bits, charcoal?potentially found something (wood) at 550mm	Fine Silty Sand
600	Very distinct transition at boundary				
600 - 760	Distinct transition to 10 YR 3/2	Plastic-like, clumps well, not rough, much more smooth, not crumbly; 90% silt		Charcoal present? Graded transition, not that distinct	Silt
760-1000	10 YR 4/3 grading from 760-790	Can feel pumice bits, same texture as above but less plastic like, more dry; 80% silt	Potentially petrified wood or burnt wood	Pumice, can see with naked eye (so reasonably large). Sampled wood/charcoal 810-860	Silt
1000-1040	10YR 3/3	Sand/silty texture, quite crumbly, sticks together in very small clumps;	Leaves of some kind	Small band of dark colour - potentially contaminated	Silty Sand
1040	VERY distinct layer, clearly defined.				
1040-1190	10YR 4/4 very slight mottling	sandy silty/clay, hardly can feel sand anymore, getting quite plastic feeling like clay; 10% clay, 90% silt		Grading into next area; Bits of black fragments, charcoal? Not many	Silt
1190-1500	Mottled 10YR 5/4 and 2.5Y 5/3	clay/silte, more clay feeling, damper/ wetter 85% silt, 15% clay		Bits of black fragments, charcoal? Not many	Silt
1500-1530	COLLAPSE				
1530-2000	Mottled 2.5Y 5/3 more dominant, with 2.5Y 5/4 and flecks of 10YR 5/6	Silt 80%, silty, plastic like	Larger black bits, charcoal or petrified wood bits?	Larger black bits, charcoal or petrified wood bits?	Silt
2000-2110	10YR 4/3	Almost pure silt	Twig - contamination	Grading from above section into this one	Silt
2110	Semi-distinct transition				
2110-2150	10YR 4/2	Silty, clay, some sand though could be silt (40% clay, 50% silt 10% sand	twig/leave	Flecks of orange	Silt
2150	Distinct transition into next area				

2150-2660	2.5Y 5/3, mottled	Silty, clay, some sand though could be silt	Black bits of petrified wood?	Grades into next section - only difference is orange colour very evident. Looks to have contamination at 2210-2230 as clump of sanyd/silty material	Silt
2660-2750	2.5Y 5/3 lots of orange oxidation	Silt, small amount of clay and sand	small flecks of black fragments		Silt
2750-2930	2.5Y 5/3 decreased amount of oxidation (smaller flecks)	Silt, small amount of clay and sand	More black fragments	Only real difference from above section is reduced orange flecks	Silt
2930	Very distinct boundary, has significant change in colour				
2930-3000	2.5Y 6/0 with 2.5Y 5/3 on the edges	Silt, small amount of clay and sand (gritty after texture); 95% silt			Silt

Appendix 5.4: Gerard Road Core physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0-162	10YR 5/3	Crummbly, top soil with clay/silt	fine roots		Top soil
162	Distinct Transition				
162-800	2.5Y 5/2 mottled with orange	>95% clay, cannot feel silt or sand, very sticky and smooth	some small fine roots	Lots of flecks of orange; oxidation	Silt
800-950	2.5Y 4/2 mottled, grading	>95% clay, cannot feel silt or sand, very sticky and smooth			Silt
950-1120	2.5Y 4/2 mottled, grading	>95% clay, cannot feel silt or sand, very sticky and smooth		Overlap of tubes as they got stuck; same as zone 800-950 (can be skipped and go straight from 950 to 1120)	Silt
1120-1140	2.5Y 4/2	>95% clay, cannot feel silt or sand, very sticky and smooth			Silt
1140	Semi-Distinct Transition				
1140-1210	2.5Y 5/3 lightens compared to zone above	90% clay, 10% silt	small parts of roots, very thin		Silt
1210-1300	5Y 4/1	Grades into large sand particles, no distinct or semi distinct boundary; overall zone 50% sand, 35% clay, 15% silt			Silty Sand
1300	Distinct Transition			Distinct end of sand	
1300-1330	5Y 5/1	Fine sand, quite compacted, have a fine, dry silt, no clay feel at all; 70% silt, 30% sand			Sand/ Sandy Silt
1330	Distinct Transition				
1330-2890	5Y 5/2	Dominance of clay; >95% clay, 5% silt			Silt
2890-3110	5Y 5/3 and 5/2	Dominance of clay; >95% clay, 5% silt		grading	Silt
3110-3230	5Y 5/3 and 5/2	Dominance of clay; >95% clay, 5% silt		grading	Silt
3230	5Y 5/3	Dominance of clay but with a gritty texture at this point		Sampled as may have pumice; no distinct change in colour	Pumice/Silt
3230-4010	5Y 5/3	Dominance of clay; >95% clay, 5% silt	Part of plant at 3540-3560	Only difference to above layer is increase of mottled orange; oxidation	Silt

Appendix 5.5: Kuaotunu 1 & 2 Cores physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0-320	Nothing			Core technically starts at 320 but at this stage am recording depths based on core lengths - will change in processing stage i.e. 320mm is actually 0mm	nothing
320-360	Dead grass - no soil				Grass
360-585	10YR 4/4	Dirt' texture 10% sand, 10% clay 80% silt	Roots present, bits of grass, lots of organics as top soil	Soil, grading from drier at top to more moist further down	Top Soil
585-600	10YR 4/4 with 10YR 5/4 as well	Increase damp, clay texture, grading transition of texture to increase of clay 40%, 10% sand rest silt	fine roots	lightens slightly, cold be part of above group	Silt
600	Distinct Boundary at 600mm				
600-700	10YR 3/2	Silt feel with gritty sand - sticky a bit like clay	fine roots	Very distinct dark layer in core	Silty Sand
700-826	mottled/speckled orange flecks (oxidisation) 10YR 4/3	more clay/sand than above section but still predominantly silt	fine roots	bits of charcoal or petrified wood - black bits; also bits of pumice, potentially reworked?	Silty Sand
826-860	mottled but with return of 10YR 3/2 parts to 10YR 4/3	still predominantly silt	fine roots	flecks of dark colour makes it look like a separate layer - could be contamination though	Silty Sand
860-1000	Mottled, flecks of orange, small bits of white/pumice - potentially reworked; 10YR 4/6 with under tones of 10YR 5/3	80% silt, can't feel sand but silty feel afterwards - bits of pumice not sand	none apart from small black bits	bits of charcoal or petrified wood (black bits)	Silt
1000-1230	10 YR 4/6; mottled, with flecks of pumice	80% silt, can't feel sand but silty feel afterwards - bits of pumice not sand		Whole part looks like cave in, would probs exclude and continue on from 1260	Collapse
1230-1260	10 YR 4/3	Predominantly silt, still gritty sand, plastic-like clay		Slight transition to darker colour; probs still contamination	Silt
1260-1748	Mottled, flecks of orange 10 YR 4/6 and 10YR 5/3	80% silt, rest sand, bits of pumice		Black bits (charcoal or petrified wood?), pumice/white bits, make rasping noise when scratching them, shells maybe?	Silty sand
1748	Colour does not change, more pumice separates these sections				
1748-1898	Mottled, flecks of orange 10 YR 4/6 and 10YR 5/3	80% silt, but a lot more pumice/shells		Graded colour transition into next section	Silty Sand
1898-1960	Some flecks of orange, 2.5YR 5/2	90% silt, decreased pumice, small amount of sand and still plastic-like clay		small bits of black charcoal/wood fragments; Gradual colour transition into next section	Silt
1960-2000	2.5YR 3/2	Nearly pure silt with minor clay feel			Silt

Appendix 5.6: Kuaotunu 3 Core physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0-300	5Y 2.5/1	Large sand particles, gritty but otherwise very smooth silt sand 60% sand, 40% silt/clay	none visible to naked eye	Transitioning boundary to next level; more of a texture difference between next level	Silty Sand (large sand particles)
300-420	5Y 2.5/1, flecks of orange	Still very sandy, more sandy than above >70% sand, rest silt/clay			Sand/Silty Sand (larger particles)
420-520	5Y 2.5/1	Decrease in sand, more like 0-300 area (sand 60% rest silt/clay)		Transitioning boundary into next level	Silty Sand (large sand particles)
520-632	5Y 2.5/2	>90% sand, almost all sand, feel large grains, undertone of silt/clay		Large stones (>8mm) found at 540 and 610	Sand
632	Distinct boundary				
632-664	somewhat mottled; 10YR 4/4 and tones of 5Y 2.5/1	60% clay/silt, 40% sand			Silty Sand
664	Semi-distinct boundary - more by texture than colour				
664-678	5Y 2.5/1	20% clay/silt,80% sand			Silty Sand
678	Distinct boundary				
678-1028	10YR 4/4	<5% sand, clay feel, bits of sand not completely smooth 95% silt		Transition into next level below	Silt
1028-1194	10YR 4/1	Similar texture as above, barely can feel any sand >98% silt		Grading transition into next level below; lightens	Silt
1194-1550	10YR 4/1 to 10YR 5/1 to 10YR 5/2 to 10YR6/3	Grading, becomes more crumbly, more silt than clay as not as sticky, 5% clay, 70% silt, rest sand (still very low amount)		Very gradual grading from 1194 to bottom of core	Silt
1550-1660	10YR 6/4	Similar texture as above, slight sand increase >5% ~70% clay ~ 25% silt	no organics found in core just large stones in higher sections - see photos		Sandy Silt

Appendix 5.7: Kuaotunu 4 Core physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0-288	5Y 2.5/2	Very sandy, >90% sand, 10% silt		Potentially tiny broken shell pieces	Sand
288	Sharp texture Transition				
288-320	5Y 3/2	Clay-like texture, >80% clay, 20% sand/silt		Shells present	Silt
320	Moderate distinct transition				
320-340	5Y 3/2 flecks of white grains/pumice	Sandy band, larger grains than 0-288 section, but have silty texture as well 30% silt		tiny broken shells	Silty Sand (large particles)
340	Distinct Transition				
340-400	5Y 3/2	Clay-like feel, >80% clay, still presence of sand/silt 20%			Silt
400	Moderate distinct transition				
400-434	5Y 4/1	Sand band >90% sand (very thick large sand grains)			Sand (large particles)
434	Semi-distinct transition				
434-460	2.5Y 4/4	80% clay/silt, 20% sand			Silt
460	Semi-distinct transition				
460-470	5Y 4/1	Sand Band >90% sand			Sand
470	Semi-distinct transition				
470-500	2.5Y 4/4	80% clay/silt, 20% sand			Silt
500	Semi-distinct transition				
500-560	5Y 4/1	Sand Band >90% sand			Sand
560	Semi-distinct transition				
560-600	2.5Y 4/4	80% clay/silt, 20% sand			Silt
600	Semi-distinct transition				
600-610	5Y 4/1	Sand Band >90% sand			Sand
610	Semi-distinct transition				
610-660	2.5Y 4/4	80% clay/silt, 20% sand			Silt
660	Semi-distinct transition				

660-700	5Y 4/1	Sand Band >90% sand			Sand
700	Semi-distinct transition				
700-740	2.5Y 4/4	80% clay/silt, 20% sand			Silt
740	Semi-distinct transition				
740-750	5Y 4/1	Sand Band >90% sand			Sand
750	Semi-distinct transition				
750-850	2.5Y 4/4	80% clay/silt, 20% sand			Silt
850-868	2.5Y 4/4 grading into 5Y 2.5/2	>90% clay/silt <10% sand; very smooth			Silt
868	Distinct Transition				
868-1030	5Y 2.5/5 with sand particles obvious	Very sandy, >80% sand, very large sand particles, small/fine gravels <20%		Shells present as well as some gravels >2mm in diameter	Sand/Gravel
1030	Distinct Transition				
1030-1170	5Y 2.5/2	50% sand, 50% clay/silt		lack of small gravels and large sand particles	Silty Sand (large particles)
1170-2300	2.5Y 4/2 grading into 2.5Y 6/2 at bottom	70% clay, 20% silt 10% sand, significantly smoother but still a bit of sand/grit texture	Part of root/plant at 1400, 1550 and 1700-1950 mm		Silt

Appendix 5.8: Kuaotunu 5 Core physical description table

Depth (mm)	Colour	Texture	Organics	Extras	Texture Triangle
0-680	2.5Y 6/3	Pure Sand		Large stone at 500 mm; Shells throughout section	Sand (larger particles
680	Distinct Transition				
680-2700	5Y 2.5/2 with splotch of 10YR 2/1 at very bottom of core	Pure sand	Piece of wood at 2550 mm	Shells throughout with some large stones >8mm at 1080, 1050-1090, 1300, 1350, 1600, 1730 and 2470-2495 mm	Sand (larger particles

Appendix 6.1: Samples from Maori Road core with associated percentage of each of the 3 categories of particle size that made up the sample.

Depth	Clay %	Silt %	Sand %
M1-0cm(average)	1.059	37.70733333	61.23433333
M1-10cm(average)	0.225333333	37.35366667	62.42133333
M1-20cm(average)	0.321333333	39.266	60.414
M1-30cm(average)	0	34.51433333	65.48566667
M1-40cm(average)	0	38.44233333	61.55833333
M1-50cm(average)	0	41.23133333	58.77033333
M1-59cm(average)	0	46.533	53.46766667
M1-61cm(average)	1.313333333	70.94	27.747
M1-70cm(average)	6.272	78	15.73
M1-80cm(average)	0.948	77.82066667	21.23133333
M1-90cm(average)	0.111666667	78.67133333	21.21766667
M1-100cm(average)	0.533666667	73.69566667	25.771
M2-102cm(average)	2.722666667	51.772	45.50533333
M2-110cm(average)	0	81.36533333	18.63533333
M2-120cm(average)	3.559	76.65133333	19.79166667
M2-130cm(average)	0	86.74333333	13.258
M2-140cm(average)	0.393666667	86.24	13.366
M2-149cm(average)	0.283333333	90.41733333	9.3
M2-160cm(average)	2.045333333	91.48133333	6.472666667
M2-170cm(average)	4.907333333	88.186	6.906666667
M2-180cm(average)	4.752666667	89.13	6.119
M2-190cm(average)	3.381	88.61466667	8.006
M2-199cm(average)	3.536333333	93.83233333	2.633
M3-205cm(average)	3.472	91.09866667	5.431
M3-215cm(average)	0.131333333	50.26133333	49.60766667
M3-220cm(average)	4.749666667	85.74533333	9.505666667
M3-230cm(average)	5.146333333	90.224	4.63
M3-240cm(average)	6.255	89.12933333	4.617
M3-250cm(average)	1.441	92.66366667	5.896333333
M3-260cm(average)	4.098666667	90.38833333	5.513333333
M3-270cm(average)	7.946	87.15133333	4.904333333
M3-280cm(average)	4.995333333	93.055	1.950333333
M3-290cm(average)	4.995666667	90.49866667	4.507
M3-299cm(average)	1.584	93.158	5.258666667

Appendix 6.2: Samples from Gerard Road core with associated percentage of each of the 3 categories of particle size that made up the sample.

Depth	Clay %	Silt %	Sand %
G1-16cm(average)	12.55	77.50766667	9.943
G1-20cm(average)	14.497	82.51966667	2.984333333
G1-30cm(average)	5.869666667	91.48966667	2.642
G1-40cm(average)	6.594666667	86.368	7.038333333
G1-50cm(average)	4.919666667	93.711	1.371
G1-60cm(average)	8.833	87.871	3.297
G1-70cm(average)	11.41266667	86.27133333	2.317666667
G1-80cm(average)	7.563666667	92.207	0.229333333
G1-90cm(average)	4.141333333	92.075	3.786
G2-110cm(average)	7.348666667	92.652	0
G2-120cm(average)	8.048666667	90.787	1.166333333
G2-130cm(average)	0	21.96866667	78.03266667
G2-133cm(average)	0	65.97566667	34.02533333
G2-140cm(average)	0	86.139	13.86266667
G2-150cm(average)	1.778333333	90.214	8.007333333
G2-160cm(aveage)	1.868666667	97.58466667	0.547333333
G2-170cm(average)	3.114666667	96.52066667	0.365666667
G2-180cm(average)	3.947	93.701	2.352333333
G2-190cm(average)	4.430666667	92.28066667	3.29
G2-200cm(average)	5.526	90.646	3.828333333
G3-210cm(average)	1.986333333	92.79	5.225333333
G3-220cm(average)	6.419666667	91.223	2.358
G3-230cm(average)	1.444666667	92.81033333	5.744666667
G3-240cm(average)	6.661	90.70033333	2.640333333
G3-250cm(average)	6.494333333	93.434	0.072333333
G3-260cm(average)	3.390333333	91.178	5.431333333
G3-270cm(average)	3.586	86.38666667	10.02833333
G3-280cm(average)	2.158333333	90.58233333	7.258666667
G3-290cm(average)	2.786	85.96633333	11.248
G3-295cm(average)	7.819	92.16066667	0.021333333
G3-300cm(average)	3.636666667	92.91033333	3.453666667
G4-310cm(average)	5.483666667	88.291	6.226
G4-320cm(average)	2.227	97.52866667	0.245333333
G4-330cm(average)	5.475333333	94.52533333	0
G4-340cm(average)	0.973	98.48	0.548333333
G4-353-357(average)	2.913666667	86.40366667	10.68266667
G4-370cm(average)	7.326333333	87.209	5.466
G4-380cm(average)	0.926666667	90.47666667	8.597
G4-390cm(average)	0.775333333	98.18966667	1.035666667
G4-400cm(average)	4.869666667	95.13166667	0

Appendix 6.3: Samples from Kuaotunu 1 & 2 cores with associated percentage of each of the 3 categories of particle size that made up the sample.

Depth	Clay %	Silt %	Sand %
K1-40cm(average)	2.719666667	84.97833333	12.303
K1-50cm(average)	10.64166667	82.51133333	6.849
K1-60cm(average)	9.902333333	79.575	10.52366667
K1-62cm(average)	10.49733333	81.884	7.620333333
K1-71cm(average)	5.443666667	76.922	17.63633333
K1-80cm(average)	7.949	78.86033333	13.19133333
K1-84cm(average)	8.209666667	77.00766667	14.78433333
K1-90cm(average)	7.66	75.586	16.75633333
K1-100(average)	1.796	48.98966667	49.21466667
K2-126(average)	6.265	68.02433333	25.711
K2-130cm(average)	2.181333333	42.44733333	55.373
K2-140cm(average)	6.408333333	64.437	29.15633333
K2-150cm(average)	2.961333333	41.83166667	55.207
K2-160(average)	4.378333333	69.32366667	26.29866667
K2-170(average)	0.995666667	73.46966667	25.53533333
K2-180(average)	1.151666667	65.18433333	33.66466667
K2-190(average)	5.811666667	74.033	20.156
K2-200(average)	4.495666667	71.67333333	23.83366667

Appendix 6.4: Samples from Kuaotunu 3 core with associated percentage of each of the 3 categories of particle size that made up the sample.

Depth	Clay %	Silt %	Sand %
K3-010(average)	0	62.74633333	37.25333333
K3-020(average)	0	66.174	33.82733333
K3-030(average)	0	77.66066667	22.33966667
K3-040(average)	0	16.206	83.79533333
K3-050(average)	0	65.922	34.07866667
K3-060(average)	0	18.11266667	81.88833333
K3-066(average)	0.729	47.621	51.65
K3-070(average)	0.667	74.66133333	24.673
K3-080(average)	5.695333333	85.815	8.491333333
K3-090(average)	7.684333333	84.30733333	8.008
K3-100(average)	0.419333333	86.435	13.147
K3-110(average)	0	80.918	19.08266667
K3-120(average)	0	53.745	46.25633333
K3-130(average)	0	43.91766667	56.083
K3-140(average)	0	51.02266667	48.97766667
K3-150(average)	0	36.33833333	63.662
K3-160(average)	0	43.03866667	56.96166667

Appendix 6.5: Samples from Kuaotunu 4 core with associated percentage of each of the 3 categories of particle size that made up the sample.

Depth	Clay %	Silt %	Sand %
K4-010(average)	0	33.36866667	66.63166667
K4-20cm(average)	0	68.81366667	31.18666667
K4-30-33cm(average)	0	47.832	52.169
K4-40cm(average)	0	68.76666667	31.23433333
K4-43cm(average)	0	8.927	91.07466667
K4-46cm(average)	0.122333333	43.522	56.35833333
K4-60cm(average)	1.630333333	63.731	34.63966667
K4-70cm(average)	0.588	62.88333333	36.52933333
K4-80cm(average)	0	69.46366667	30.53666667
K4-90cm(average)	0	6.945666667	93.05466667
K4-95cm(average)	0	16.77833333	83.221
K4-100cm(average)	0	21.42366667	78.57733333
K4-110cm(average)	0	38.471	61.52933333
K4-120cm(average)	0	80.80233333	19.19866667
K4-130cm(average)	0	81.11566667	18.88366667
K4-140cm(average)	0	85.34333333	14.657
K4-150cm(average)	0	32.69333333	67.30766667
K4-160cm(average)	0	36.009	63.991
K4-170cm(average)	0	28.27	71.72966667
K4-180cm(average)	0	31.40166667	68.599
K4-190cm(average)	0	23.212	76.78766667
K4-200cm(average)	0	40.319	59.68233333

Appendix 6.6: Radiocarbon dates calculation for material found in the Maori Road and Gerard Road cores. Calculations were carried out by Waikato University and presented by Tereza Novakova.

Core	**Coordinates**		**Sample depth below ground (m)**	**Sample material**	**Material type**	**Sample condition**	**Collected**	**Laboratory identifier**	**Conventional 14C age (BP)**	**Calibrated 14C age (2σ) in calendar years BC/AD**	**Oxcal probability (%)**	Calibrated 14C age (calBP, 68%)	**cal BC/cal AD**
G2	37°22.685' S	175° 39.121'E	1.0 m	wood	organic-rich sand in floodplain outside stop banks	dry, anoxic	24/03/2014	Wk-39424	7940±30	**7030-6875 BC**	42.1	8704-8932	**6868±114 BC**
										<u>6865-6692 BC</u>	53.3		
M2	37°22.759' S	175° 39.524'E	1.6 m	rootlets	organic rich silty clay, floodplain core within stopbanks	dry	29/03/2014	Wk-39428	5178±26	**4041-4011 BC**	27	5922-5979	**4001±28 BC**
										<u>4005-3956 BC</u>	68.4		