Hot Pursuit of Rangitaiki Plains Subsidence, Measured by Buried Beach Facies

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Abstract

The Rangitaiki Plains are situated in the actively subsiding Whakatane Graben in Bay of Plenty, New Zealand. Despite that subsidence, massive influxes of sediment from the Taupo Volcanic Zone (TVZ) has driven progradation of the coastline 9.75km in past 8,000 years. Inshore there are several paleo-dune and beach sequences that mark the location of past coastline. Sea level has remained static for the last 6,500 years so that the beach height has also remained the same. However, the numerous faults in the Rangitaiki Plains have caused land uplift and subsidence. This has changed the original heights of those paleo-dune and beach sequences. LiDAR has recently been used by Begg and Mouslopoulou to measure the offset between these dune sequences. This project uses GPR to measure the offset between buried beach facies to find at a more accurate result than LiDAR, which can only measure offset to weathered dune tops. The aim of this GPR study was to measure displacement in an east-west direction. It was found there was not subsidence to the east as was expected. A transect perpendicular to the coast was used to compare LIDAR and GPR measurement methods showed inconstancies with the LiDAR.

Site Background

The Rangitaiki Plains in the Bay of Plenty region of New Zealand is a 14 mile wide plain, located between the towns of Matata and Whakatane. On either side of the lowland, north-south oriented fault scarp ridges confine the plains. Extending back from the ocean are paleo-dune sequences, paleo-beach deposits, peat swamps and flood plains. The variety of environments found on the Rangitaiki Plains are testament of the thousands of years of progradation that has advanced the coast to where it is today. In the last 8,000 years the coast has advanced 9.75km. This coastal advancement has occurred at the same time that the Rangitaiki Plains have been actively subsiding because they are situated in the Whakatane Graben (Pullar and Selby 1971).

The Whakatane Graben is formed by the convalescence of two major New Zealand geologic features. One is the Taupo Volcanic Zone, (TVZ) which is an active rift valley that takes a northeasterly bearing to connect Mt. Ruapahu up to White Island. The other force of geologic nature is the North Island Shear Belt running in a north-south direction. As seen in Figure I, these two fault and volcanic zones intercept in the Bay of Plenty area, and for possibly as long as the last million years have caused the Whakatane Graben subsidence (Nairn and Beanland 1987). Lemarche et al. also cite that the Taupo fault Belt and the North Island Dextral Fault Belt are active fault systems in the region (2006). Regardless of the names assigned to faults in the Whakatane Graben, it is clear that the Rangitaiki Plains are ripe with a multitude of very active faults.

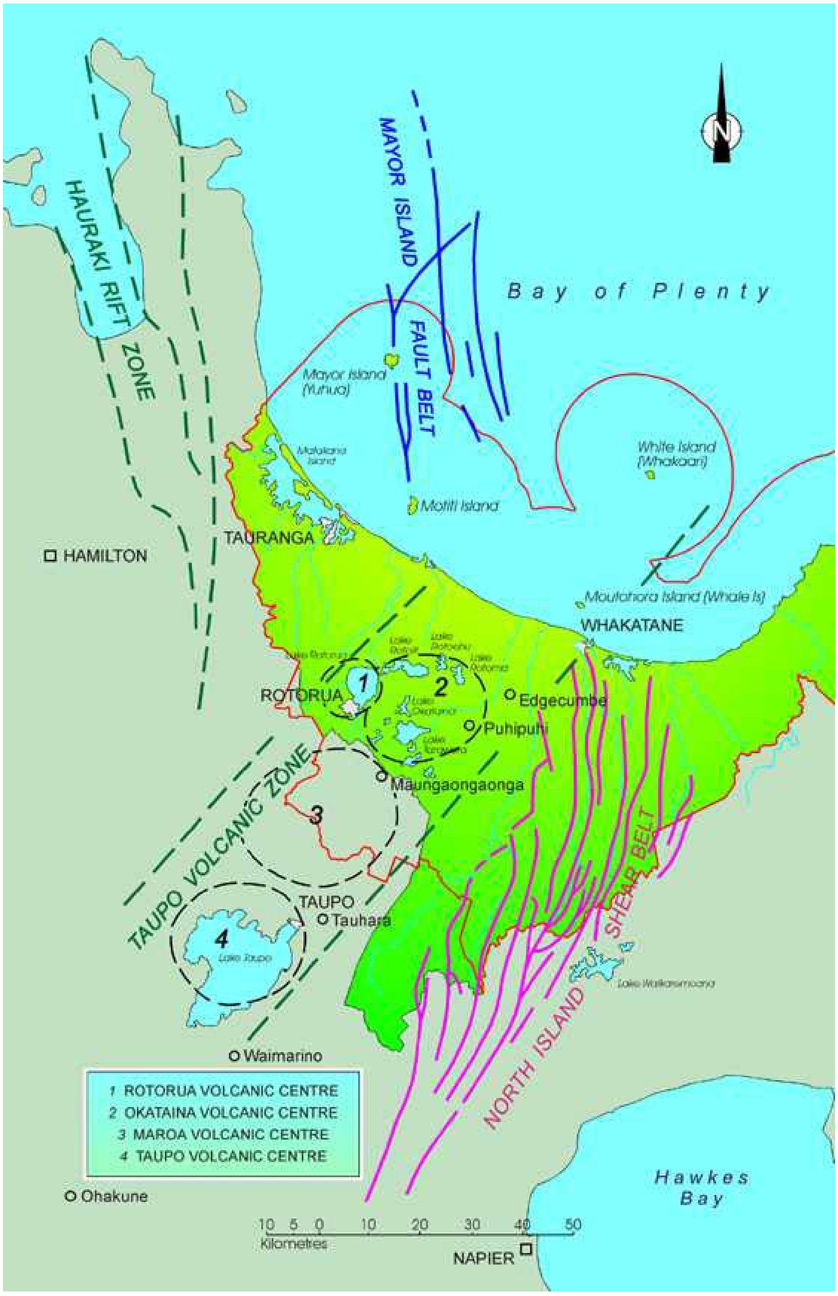

Figure I: Central North Island New Zealand Fault Activity (ENV Bay of Plenty)**.** TVZ and North Island Shear Belt meet to form the Whakatane Graben. TVZ also conveys volcanic sediments from North Island interior to coast to the prograding Rangitaiki Plains.

The TVZ is a calc-alkaline volcanic system, which has been active for about the last 2 million years. Geothermal activity and earthquakes occurring less than 10 km down into the crust have been extremely common occurrences in the TVZ (Lemarche et. al 2006). Northern TVZ andesitic cones like Mt.

Edgecumbe are one source of volcanic activity, so are the rhyolitic volcanoes, Mt. Tarawera and Haroharo. Tarawera erupted most recently in 1886 causing significant sediment to be transported out to the Rangitaiki Plains (Nairn and Beanland 1989). Taupo ignimbrite and the other caldera volcanoes of the TVZ have also supplied the Whakatane Graben with sediment (Pullar and Selby 1971). Seismic imaging has found that the Whakatane Graben's basement is Mesozoic greywacke with volcanic intrusions. That basement is covered by 3km of coastal and alluvial sediment (Davey et al., 1995).

Pullar and Selby found that progradation of the coastline would occur rapidly following each eruption event (1971). The progradation events left behind 4 paleo-dune sequences that are still visible on the eastern side of the Rangitaki Plains. The team also found, with tephrochronolgy and carbon dating, the paleo-dunes ranged in age between 900 and over 5,000 years old, as seen in Figure II. After their careful analysis of the Rangitaki Plains paleo-dunes, Pullar and Selby concluded that further research was necessary to understand the relationship between progradation, eustasy and land subsidence and uplift (1971). This is a challenge because the thick alluvial sediments on the Rangitaiki Plains hide many faults. The hidden faults make creating a record of past sea level and progradation difficult since the record of land displacement is not understood without them (Nairn and Beanland 1987).

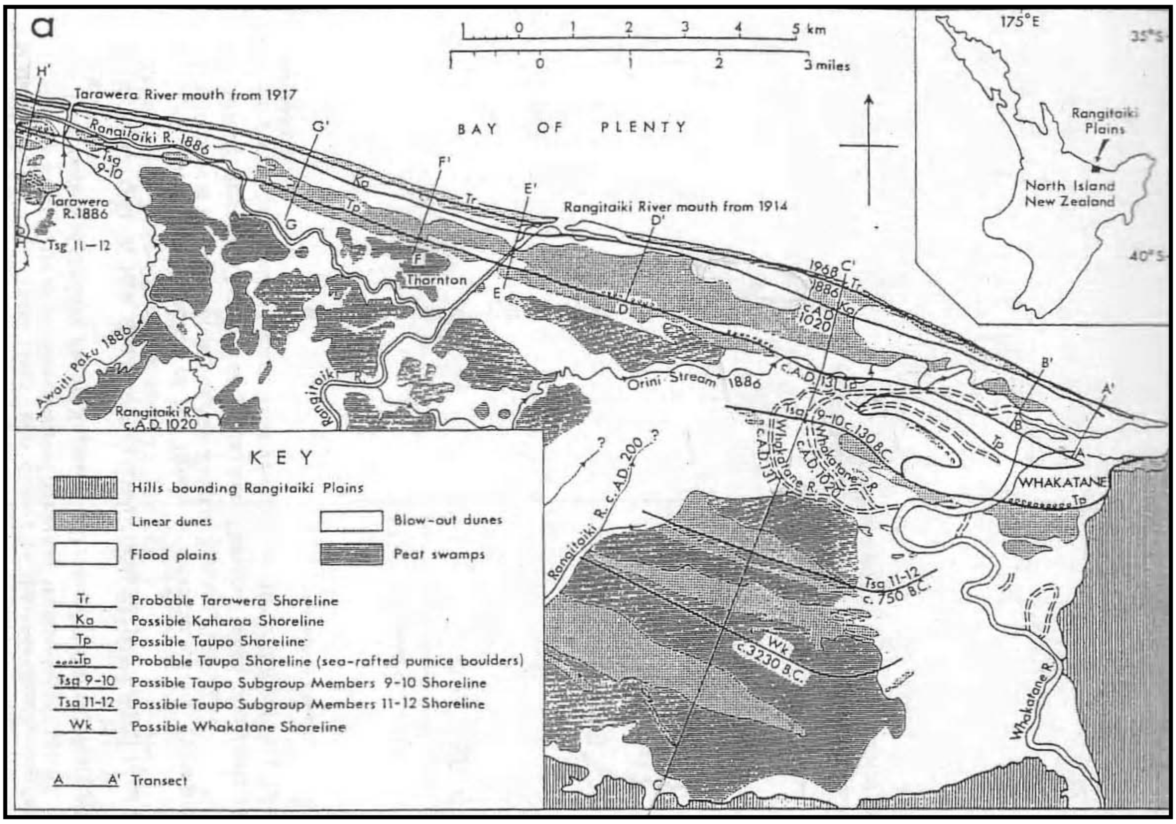

Figure II. Pullar and Selby's map of Rangitaiki Plains dune features. Transect C-C' is revisited with GPR in this paper and with LiDAR data by Begg and Mouslopoulou.

Introduction

The yet to be published paper on LiDAR of the Rangitaiki Plains by Begg and Mouslopoulou is the most recent attempt to hone the geologic history of the Whakatane Graben. Begg and Mouslopoulou's paper entitled "LiDAR reveals subtle late Holocene faulting within an active rift, Taupo Rift, New Zealand," discovers numerous new faults in the region. The map of surface morphology created from LiDAR is down to centimeter accuracy and was used to find the surface offsets of faults. From the offsets Begg and Mouslopoulou were able to ground truth some of the new faults with trenching. Part of the paper addresses the use of paleo-dunes and beaches to measure subsidence or uplift during the last 5,000 years. Major sedimentation occurred on the Rangitaiki Plains followed the Whakatane, Taupo and Kaharoa eruptions and caused rapid progradation (Nairn and Beanland 1987).

The rapid progradation left behind beach and dune facies. Sea level has been consistent for the last 6,500 years so as the beach pushed out into the ocean it remained on an equal vertical plane. In the thousands of years that followed after the facies were deposited, numerous earthquakes have occurred in the Whakatane Graben. These earthquakes caused uplift and subsidence in different locations. The equal vertical plane of deposition set, by static sea level, was disrupted after the long period of faulting. With this justification, Begg and Mouslopoulou attempted to quantify the adjustments to this vertical plane by comparing the tops of paleo-dunes with LiDAR surface topography data. Begg and Mouslopoulou's only consideration before measure vertical displacement to the top of the several thousand-year-old dune sequences was that compaction of sediment could effect measurements. Their results are in Figure X in the Results section. However, the sediments on the dune sequences were deemed unlikely to have undergone recent compaction like the peaty parts of the plains may have. Weathering or other removal of the top dune sediments was not considered (Nairn & Beanland 1989; Begg and Mouslopoulou Unpub).

This project examines a more accurate method for measuring displacement across the Rangitaki plains. It is illogical to think that after thousands of years there has been no change to the original surface of paleo-dune sequences. Ground penetrating radar (GPR) provides the ability to map subsurface layers unaffected by weathering and erosion. Rather than using suspect topographic surfaces much more accurate paleo-beach face surfaces are compared between sequences to measure vertical offset. It is expected that the offset values will be different and hypothetically more accurate. This project will build on work by Mindi Summers and Amy Dougherty, who collected and plotted GPR results along the original C-C' transect also used by Begg and Mouslopoulou in their study. Results from that transect will be discussed, as well as a new data set that poses a different question. The new GPR transect on Angle Road, located on the oldest paleo-dune sequence to the northwest of C-C'. With this transect the question of whether there is any hidden offset along an east-west direction to the northwest of C-C’ will be addressed.

Aims

- Discuss the difference in offset measurements found using LiDAR and those found using GPR of buried beach facies.
- Determine if there is any offset east-west along the oldest dune sequence (D) and consider an explanation of the results.

Methods

Ground Penetrating Radar (GPR) was taken along a transect running the length of Angle Road near Whakatane, Bay of Plenty, NZ. The GPR data was collected over several days in February, 2009. Locations and labels of the transect data can be found in Figure III and IV. A drag along, mobile, GSSI SIR-2000 GPR system with a 200MHz antenna was used. At marked intervals of 100m, manual input of a marker into the data output allowed for the data to be normalized to accurate distance points. The processing of the GPR data, normalizing, and topographic adjustments were all preformed in RADAN 6.5 software. Microsoft Power Point was used to arrange sections of GPR transect and apply scales.

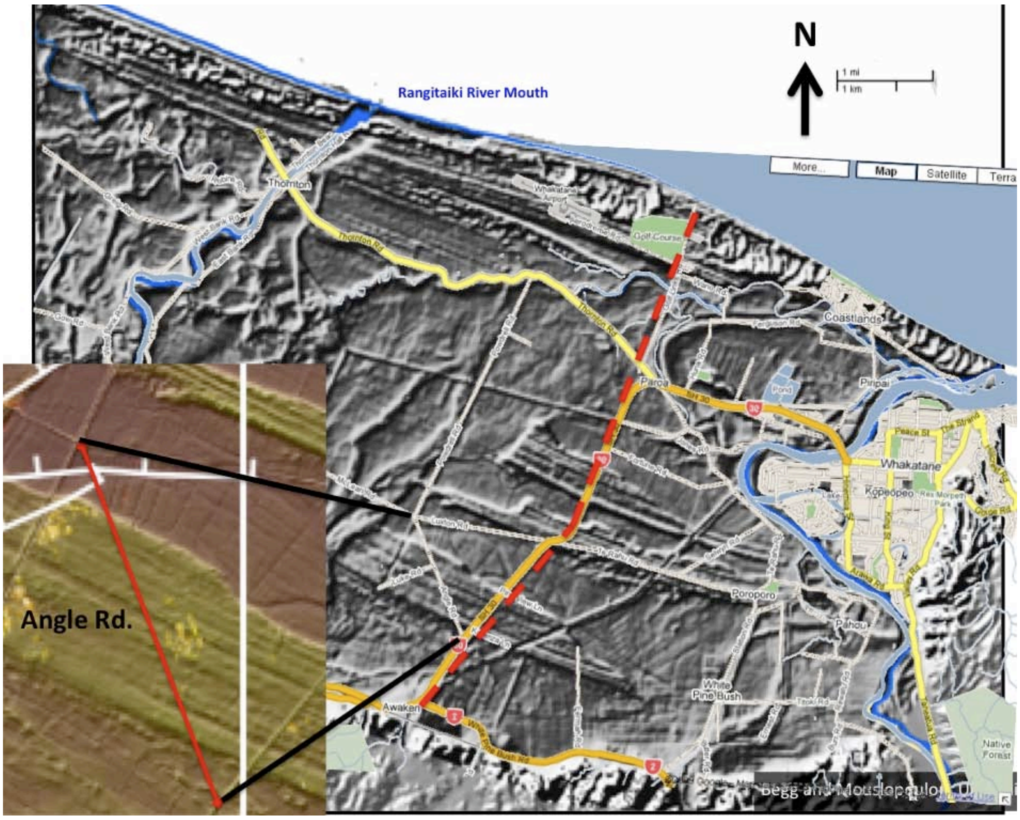

Figure III. Map of the Rangitaiki Plains. Angle Road transect is shown and the red dashed is transect C-C’.

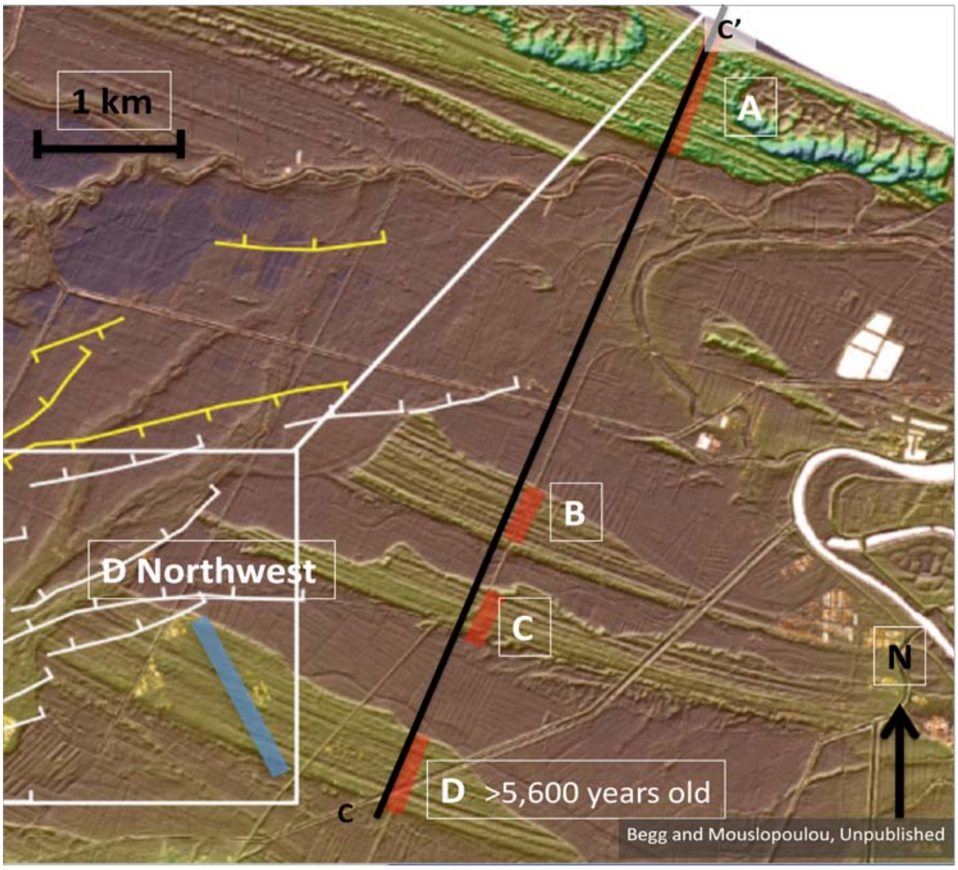

Figure IV. Transects and paleo-dune sequence labels. Angle Rd. transect is shown in blue and its paleo-dune sequence is labeled D-Northwest.

Topographic data recorded for the Angle Rd. with a Sokkia Electronic Total Station was required to topographically correct the GPR data in RADAN. The total station topographic information also linked Angle Rd (D Northwest) to the C-C', (D through A) transect so their beach facies data could be compared. Depth of the GPR record was determined with the known dialectic constant of 6 for beach sands; Dougherty has shown this constant to be accurate after repeated comparison with core data.

Dunes and beach facies were identified and interpreted according to criteria used by Dougherty and Nichol, and Van Heteren et al (2007, 1998). A vibra-core of 2.25m was taken near the beginning of the Angle Rd. transect and was core logged and photographed. The grid plotting capabilities in the computer program MatLab were utilized to input points along the top of dune sequence D-Northwest beach facies. The procedure for where to input points was to scroll along the GPR transect and place a point on each peak and valley evident in the beach facie. Picking each peak and valley was thought to create a reasonable average of the data, although the input of points was still very dependent on judgment of the researcher. MatLAb provided graph-able spreadsheet data with depth adjusted with the dialectic constant.

Results

The results section includes core log photos, GPR results, and graphs of MatLab derived beach facies height comparisons.

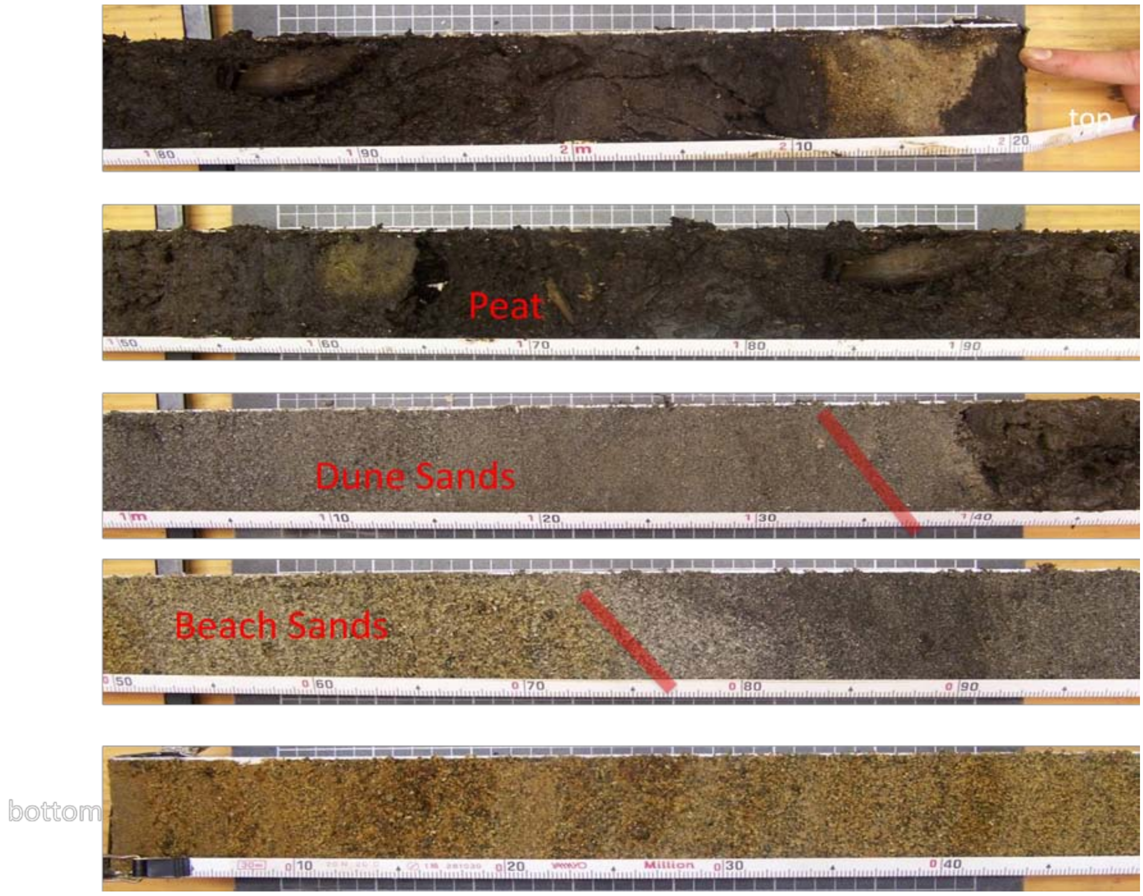

Figure V. Angle Rd. Core Photo The top of the core is at the right of the top image and the bottom is at the left of the bottom image. Peat was found over top of dune and beach sands.

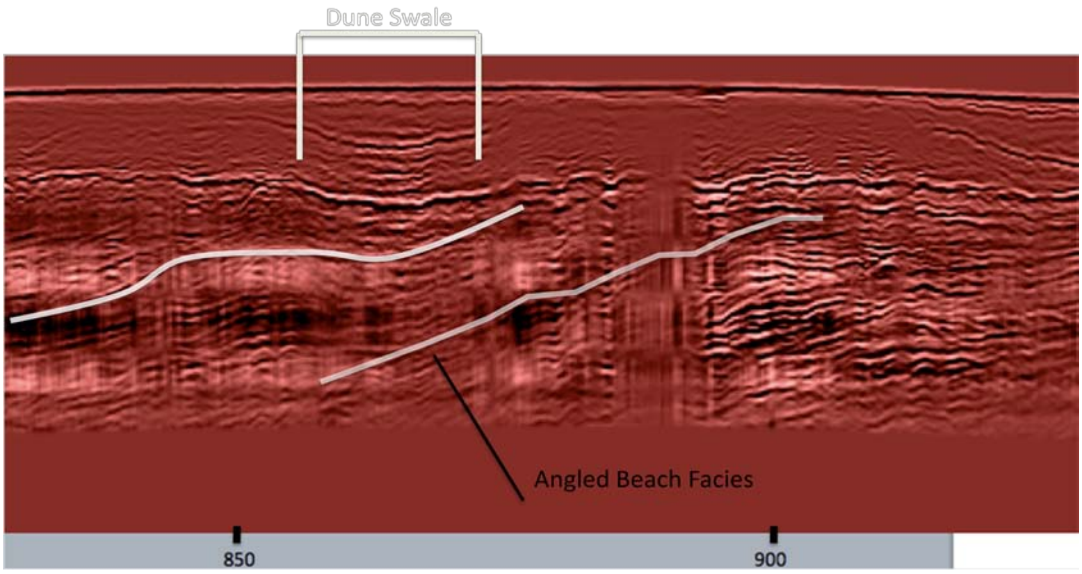

Figure VI. Expanded view of GPR results. Taken further along transect than core where no peat layer is present. A dune swale is bracketed and the underlying beach facies are highlighted.

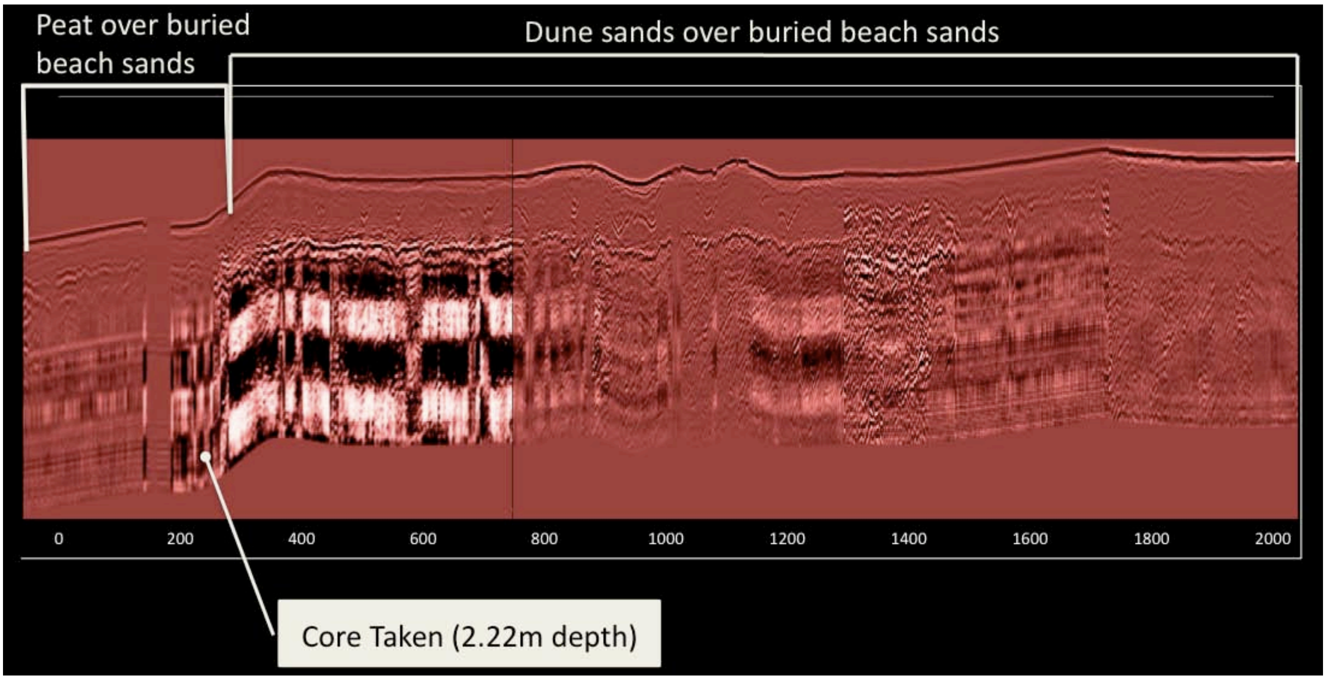

Figure VII. View of entire Angle Rd. transect with sections bracketed.

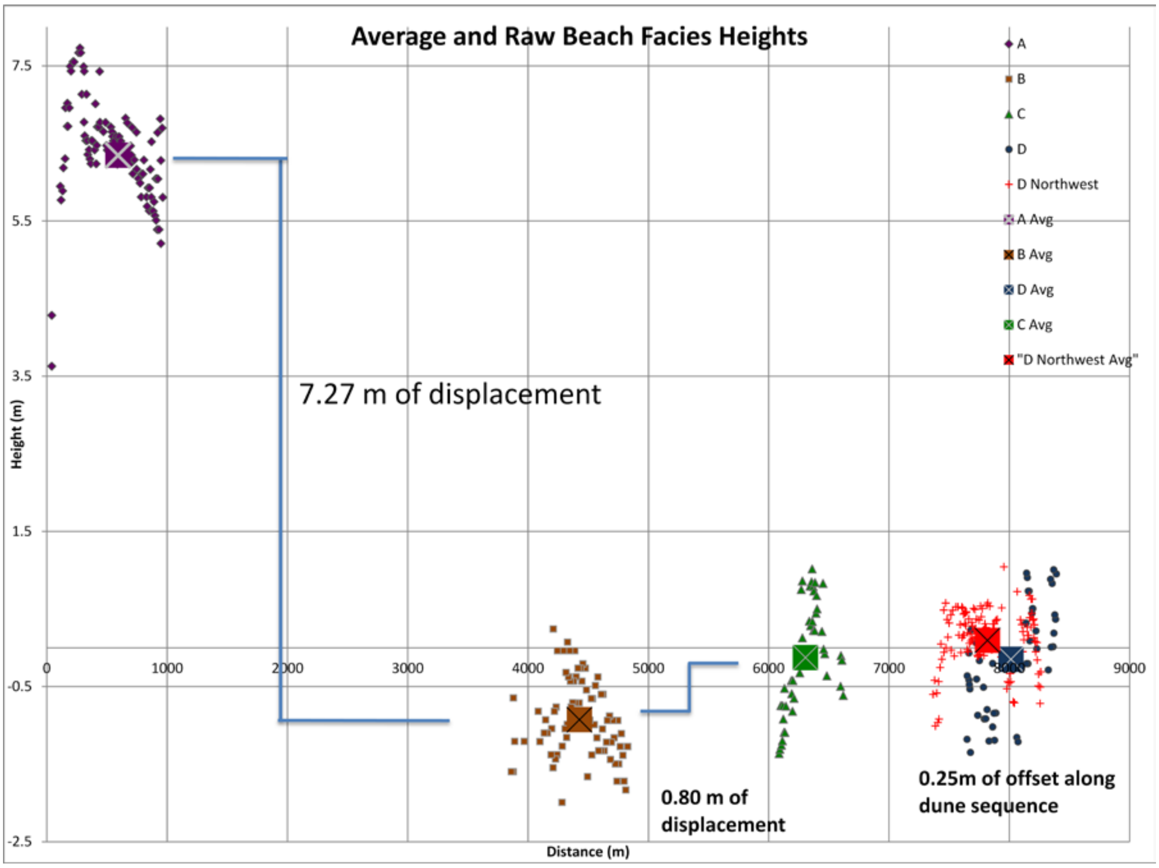

Figure VIII. Plot of all Paleo-dune sequences and averages. Displacement data is arrived at from averages.

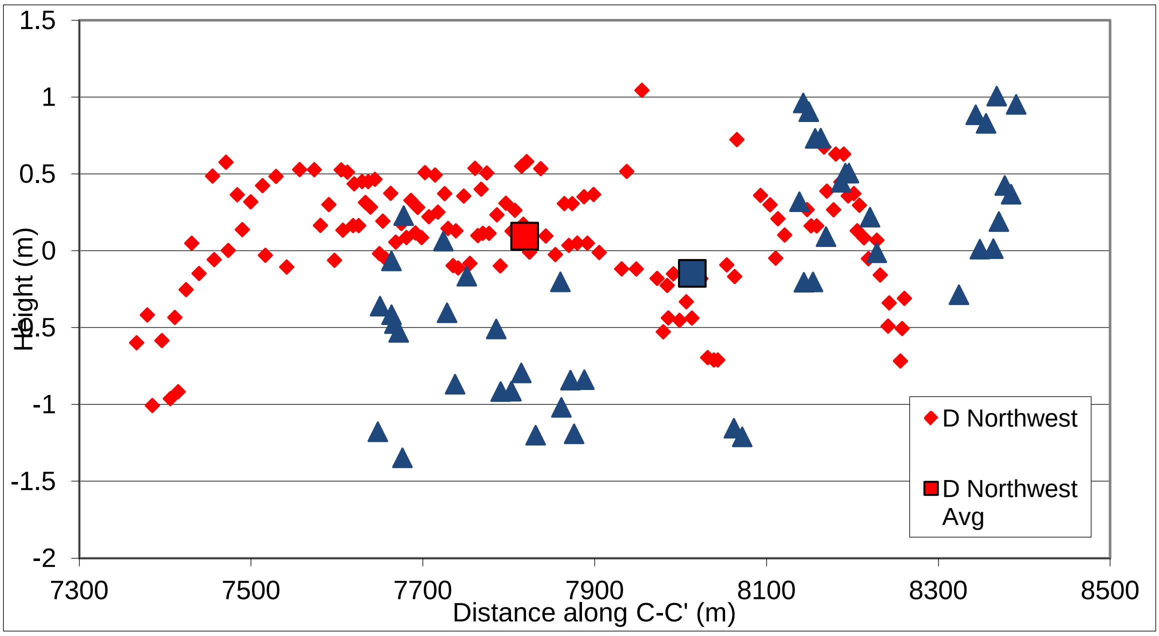

Figure IX. Plot of only the D paleo-dune sequence. D Northwest (Angle Rd.) is seen in Red and D (oldest C-C' dune sequence) is in Blue.

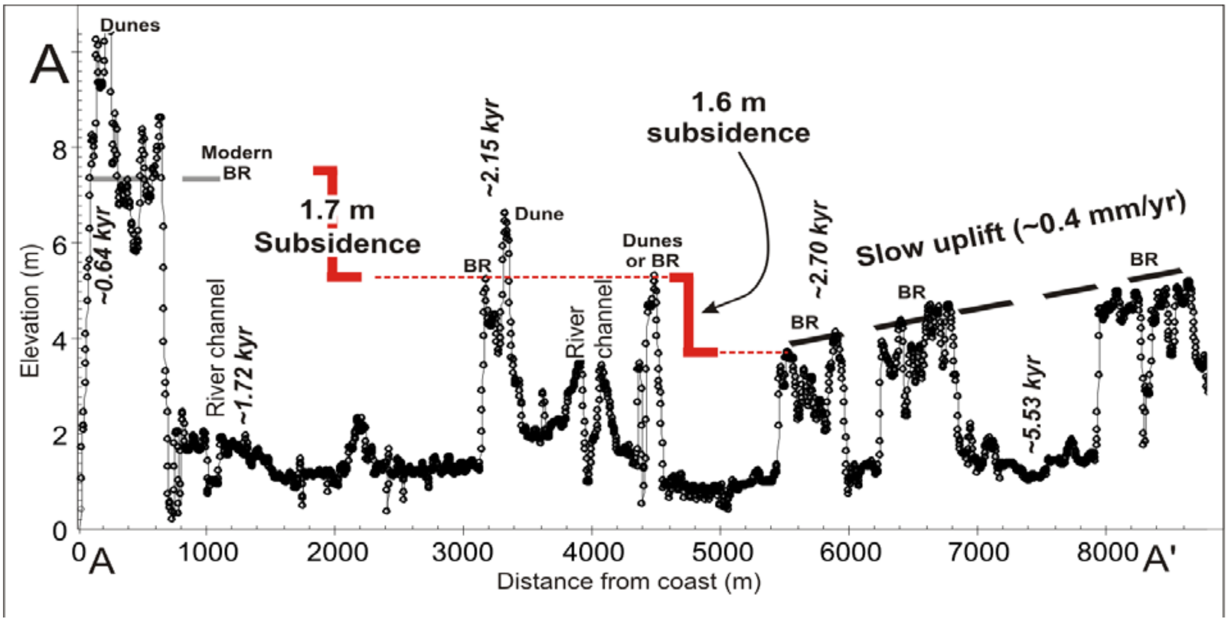

Figure X. Begg and Mouslopoulou C-C' displacement chart. Shows a total of 3.3m of uplift between B and A sequences. The first, A, sequence is plotted to its beach height, B, C, and D are all plotted to dune top.

Discussion and Conclusions:

Angle Road, GPR transect data records two different stratigraphy patterns. Before 300m the transect shows a peat layer on top of dune and beach layers. This is supported by core data in Figure V. After 300m the rest of the transect records a stratigraphy of dune sands over laying beach sands (Figure VII). The presence of dune swales and downward sloping beach facies seen in Figure VI is evidence for this conclusion. This analysis of Angle Road's, D northwest stratigraphy, provides the understanding required to accurately map the buried beach facies.

East-West Subsidence? Subsidence in the D-Northwest paelo-dune transect relative to the D transect back to the southeast was a possibility. Documented subsidence does occur further to the west in the Whakatane Graben, but from the results shown in Figures VIII and IX it is evident that it does not occur between the Angle Rd. transect and C-C'. The opposite actually occurs. The average height of the D-Northwest paleo-beach transect is 0.25m higher than the D transect back east. From fault analysis with GPR by Fandel, there was no obvious faulting along the Angle Road transect that would have caused uplift. Although, as Fandel concluded, it is extremely difficult to find or fit GPR images to standard identification criteria (2009). Begg and Mousopoulou's LiDAR data did not find evidence for a fault between the transects either.

It could just be possible that there was some variation in the original deposition of the beach facies along the shore. If this were the case it could begin to threaten the assumption that there is a constant vertical plane of deposition for each beach facies to compare. The confidence in subsidence or uplift measurements is weakened as potential variables like along shore beach height variation are considered. There is already the large assumption that sea level has been static for the last 6,000 years. Alternatively, the methodology used could have limited the accuracy of the result, specifically when the top heights of the beach facies were plotted in MatLab. For example in Figure IX it is clear that D-Northwest had numerous more data points. When plotting in MatLab it ultimately comes down to the researcher's judgment on where to place the top of a beach facie or how many points to plot. Between D-Northwest and D there were two different researchers plotting the facies heights, this could have contributed to the difference in height. Or perhaps there really is a buried fault somewhere. Or perhaps because Angle Road transect was not perpendicular to the dune sequence like C-C' some variation arose. Further research would be required to truly understand why along the same paleo-dune sequence there was minor uplift of 0.25m.

LiDAR vs. GPR beach facies Displacement Measurement

Begg and Mousopoulou's paleo-dune measured displacement is seen in Figure X. There are some clear inconstancies in the results. The slope line fit to the back three dune sequences, B, C and D is poorly plotted, the line does not even touch the data points at the last dune. Begg and Mousopoulu nonetheless, conclude a slow up lift rate exists between B, C and D at a rate of 0.4mm/yr. GPR plotting of displacement between B, C and D in Figure VIII show a much different story. Between C and D beach facies there is no noticeable change in elevation. The only between B and C beach facies is there an offset of 0.80m. From GPR beach facies analysis there is no slow uplift across the three back dune sequences.

The other point of contention in the Begg and Mousoloulou LiDAR displacement measurement for the C-C' transect is between B and the youngest A dune sequence. According to Begg and Mousoloulou there is an uplift measuring 3.3m between dunes B and A. Correlating the dune top of the B sequence to the beach facie in sequence A to collect this measurement causes serious inconstancy. GPR beach facies analysis finds B to A uplift is more than twice as large as that derived by LiDAR. There was 7.27m of uplift calculated between them. The questionable offset measurements offered by Begg and Mousopoulu for the C-C' transect confirms the logical suspicions of LiDAR as a poor method for accurately quantifying offset between dune sequences which are thousands of years old. The comparison of high resolution topographic data of dune sequence tops, from LiDAR, is limited by the low morphological resolution of weathered dune tops thousands of years after their deposition. The youngest dune sequence's morphology still matched the resolution of underlying statigraphy, but the older the dune sequence, the worse the resolution of the dune morphology becomes in relation to the buried statigraphy. Therefore, GPR plotting of buried beach facies is more accurate than LiDAR for measuring displacement.

Further research and consideration of critical assumption. To improve this study in the future multiple GPR transects, all perpendicular to the dune sequence could be used to more confidently measure east-west displacement. The methodology could also be improved to create a specific procedure when plotting the tops of beach facies in MatLab. These two suggestions have the potential to greatly increase the accuracy and precision of an east-west subsidence study. Begg and Mousopoulou also calculated displacement values along other transects, the GPR method could be tested on those additional transects.

Also, It seems likely that future research on New Zealand Holocene sea level changes could affect the accuracy of this papers results. Gibbs' work on sea level found sea level has been consistent for about 6,500 years. Yet, there has been variation of up to 1 meter, as well (Gibbs 1986). The literature review of New Zealand Holocene sea level studies by Kennedy concluded that a record specific to New Zealand needs to be developed. Sea level fluctuations relate directly to the accuracy of using paleo-dune or paleo-beach sequences for displacement measurement. As Kennedy states, "In New Zealand, the understanding of sea level variation is…critical in the calculation of rates of uplift and hence palaeoseismicity (2008)." In the future when a more specific sea level record for New Zealand is developed this study, using GPR'ed beach facies to measure displacement, will need to be revised because the static sea level assumption will likely no longer be true.

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