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Ground Penetrating Radar Observations of Present and Former Coastal Environments, Great Sandy National Park, Queensland, Australia – Focus on Moon Point, Fraser Island

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ABSTRACT

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The world's large sand islands and mainland sand masses dominate the coastal system of southeastern Queensland with dunes exceeding 240 m in height. Previous work using sediment cores and TL/OSL dating has estimated the age of the dunes at 730,000 years. This system, the world's largest down-drift sand system, has Fraser Island and the Cooloola Sand Mass as the two northern-most members. Combined, these form the Fraser Island UNESCO World Heritage Site and the Great Sandy National Park. Between 2012 and 2015, a series of high-resolution, reconnaissance-level GPR lines were acquired on Fraser Island and on the northern end of the Cooloola Sand Mass; totalling over 75 km. The lines provide insight into sea-level fluctuations that drive large-scale coastal evolution and reveal the presence of past shoreline complexes that are proposed to be associated with the mid Holocene highstand and the previous interglacial. The generalized sequence is interpreted as a variable thickness of aeolian sand over beach deposits with a transgressive unconformity at the base of the beach deposits, which is interpreted as the Mid Holocene-to-present system. The Mid Holocene system overlies an older system that has variable preservation and is composed of beach deposits with a transgressive unconformity at the base. In places, portions of the sequence are lightly consolidated with organic material, locally known as "coffee rock". The coastal sequences hold the potential to host an archive of storm, sea level and sediment supply records over at least two interglacial periods.

ADDITIONAL INDEX WORDS: *Fraser Island, Coastal Change, Sea Level Change, Palaeoenvironments*

INTRODUCTION

Coastal systems are some of the most dynamic environments on the planet. Changes in water level on time scales ranging from seconds to thousands of years are constantly reshaping the landscape. In low latitude sandy systems such alterations can be preserved within the sedimentary record of the coastal zone. Unraveling the history of change and linking changes to processes and climate variation is key in developing an understanding of how the environment will change in the future.

Great Sandy National Park is located in southeast Queensland, Australia (Figure 1). It is composed of two major sections; Fraser Island (K'Gari) and the Cooloola Sand Mass (Johnson, 2009; Gontz *et al.*, 2015). Fraser Island is the world's largest sand island and is the terminal island in the world's

largest down drift sand system. Sand, eroded from sandstone deposits in eastern New South Wales is carried north by long shore transport to form numerous pocket and barrier systems south of the New South Wales-Queensland border (Harris *et al.*, 1996). North of the border, the depositional style shifts and large sand islands and coastal sand masses dominate the coast (Harris *et al.*, 1996; Johnson, 2009).

Research on the timing of emplacement of the sand islands of the Queensland coast has suggests the islands have grown during times of lower sea levels due to increased sediment availability from the exposed continental shelf (Ward) or from highstand strandlines (Thompson, 1981). The sediment is mobilized by aeolian processes and dunes on the islands expand. Moreton Island, south of Fraser Island, shows a strong correlation of dune forms to changing aeolian regimes in recent years (Levin *et al.*, 2014) while the core of the island contains dunes older than 400,000 years (Brooke *et al.*, 2015).

Over the past ~130,000 years, global sea levels have fallen from slightly above present to ~125 m below present and then

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risen to modern levels (Bard *et al.*, 1990). The record in Australia is different (Lewis *et al.*, 2013). Sea levels were high ($\sim +5$ m) during MIS5 and dropped, following the global pattern to reach a lowstand (~ -120 m) that coincided with the Last Glacial Maximum (Lewis *et al.*, 2013). During the post-glacial warming, sea levels rose and passed present levels approximately 8000 years ago and continued to about 1.5 to 2 m above present levels at about 7000 years ago. For the past 7000 years, sea levels in eastern Australia have been falling (Lewis, *et al.*, 2013; Switzer *et al.*, 2010). It is only in the past few decades that tide gages suggest an end to the falling levels and the beginnings of a rise (Gontz *et al.*, 2015).

Ground penetrating radar (GPR) has proven to be a useful tool in assessing the stratigraphic architecture (Gontz, *et al.*, 2014; Hein *et al.*, 2012), reconstructing palaeoenvironments (Switzer *et al.*, 2010) and interpreting processes (van Dam *et al.*, 2003).

As a part of a larger effort to understand the Great Sandy system, we began a campaign to map areas of the region to develop a stratigraphic understanding. The knowledge gained from the GPR-based stratigraphy will be used to develop a targeted surface and subsurface sampling regime. The samples will be used to extract subsamples for chronological control, analysis for climate and palaeoenvironmental proxies and ultimately create a robust palaeogeographic reconstruction.

METHODS

Over the course of several years (2012–2014) ground penetrating radar surveys have been conducted in Great Sandy National Park to relate Quaternary landscapes and evolutionary processes to climate variation. Nearly 75 km of radar profiles were acquired using MALA Geoscience GPR, ProEX and GX systems with antenna frequencies ranging from 160 MHz to 500 MHz. All GPR data was acquired using time-firing (10Hz) and integrated DGPS for positioning. GPR antennas were hand-towed in areas of rough terrain or narrow trails. Where possible, antennas were vehicle-towed. In both cases, survey speed was maintained at approximately 4 km/hr.

GPR data were post processed using GPR Slice v7. Radar lines were de-wow'ed, gained with a user-defined gain, bandpass filtered, depth-time corrected, topographically corrected, and spatially corrected. Radar data were exported as image files for qualitative and stratigraphic analysis as well as reflector mapped in GPR Slice and exported as ascii text files for spatial analysis in ArcGIS 10.

Due to dense vegetation and steep aeolian topography, initial GPR surveys were focused along existing unimproved roads and trails. A focus was placed on areas identified from aerial photographs that showed evidence of beach ridge topography and small topographic breaks below 10 m in elevation. This included the areas of Moon Point and Dilli Village on Fraser Island and Inskip Point, Rainbow Beach, Freshwater Beach and Teewah on the Cooloolo Sand Mass. This manuscript will focus on the information extracted from 10 GPR lines with a total line length of 4.6 km that were collected during July 2014 in the Moon Point area of Fraser Island. (Figure 1).

RESULTS

GPR data from Moon Point, Fraser Island were acquired perpendicular to the present-day coastal system along the Moon

Point-Happy Valley Road. The survey began at the present-day beach and terminated at the intersection of the Moon Point-Happy Valley Road and Bullock Road. A major break in slope occurs within 50 m of the road intersection (Figure 1).

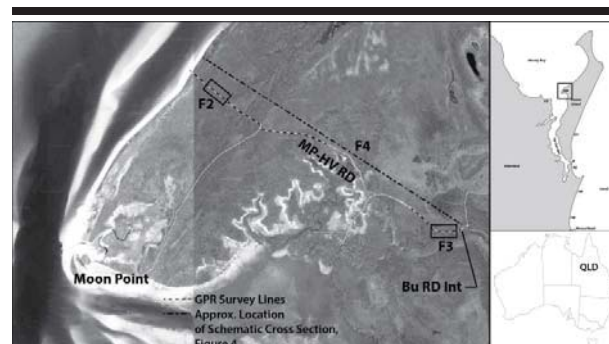


Figure 1. The Moon Point study area. (a) shows the generalized southeastern Queensland coastal system. (b) shows the location of Moon Point on Fraser Island. MP-HV RD is Moon Point to Happy Valley Road; Bu RD Int is Bullock Road Intersection. Boxes F2 and F3 indicate figures.

Analysis of GPR lines resulted in the identification of five (5) radar facies. Each of the facies is characterized by the geometric relationships of the internal reflections, relationships between internal reflections and facies bounding surfaces and the intensity of reflections (Figures 2 and 3).

FACIES1 – was observed on each of the 10 radar lines acquired along the Moon Point-Happy Valley Road. The upper bounding surface was coincident with the ground surface in all cases. The lower bounding surface was variable, but generally parallel to subparallel with respect to the ground surface. Internal reflections were parallel to subparallel with respect to the ground surface. Reflections exhibited extremely high intensity. Intensity of reflection was reduced from the upper bounding surface toward the lower bounding surface.

FACIES2 – was observed noncontinuously throughout the 4.6 km survey. When present, the upper bounding surface was coincident with the lower bounding surface of FACIES1. Internal reflection were generally wavy to subparallel with low intensity. Internal reflection were generally tangential to the lower bounding surface. Discontinuous areas of transparency to very low reflector intensity exist. The lower bounding surface was of medium intensity and exhibited an unconformable contact with the upper bounding surface of underlying facies.

FACIES3 – was observed in the northwestern portion of the survey transect. When observed, it was continuous. The upper bounding surface truncates internal reflection and internal reflections of facies above are tangential to the upper bounding surface. Internal reflections are characterized by seaward (NW) dipping sigmoidal clinoforms. The pattern of internal reflections is not consistent and exhibits numerous minor internal truncation surfaces. Internal reflections are generally tangential with the lower bounding surface. The lower bounding surface is continuous and exhibits a medium to high intensity. It truncates reflectors in the facies that underly FACIES3.

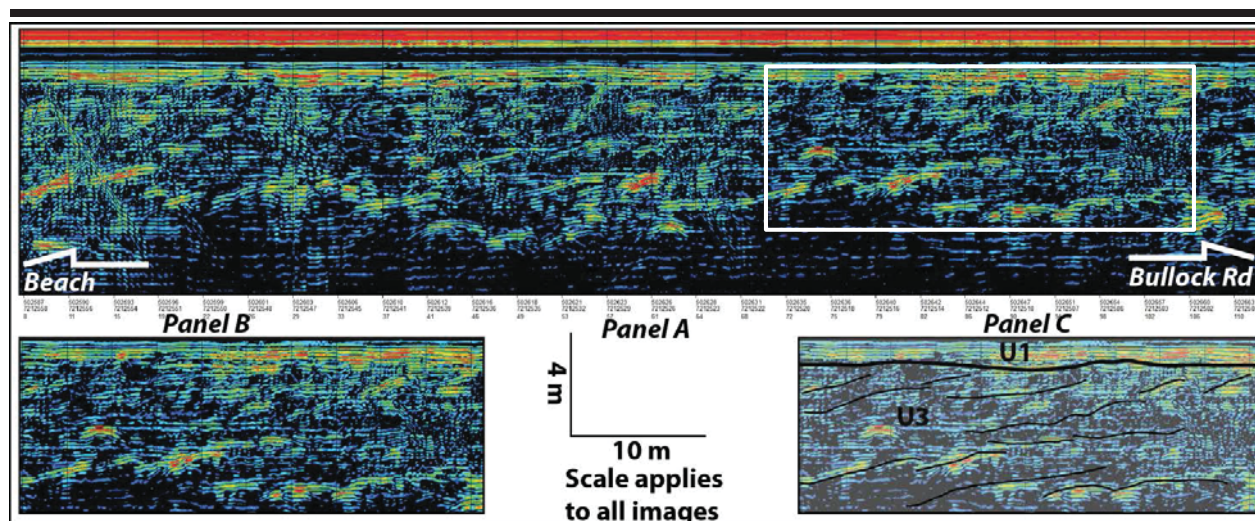


Figure 2. Ground penetrating radar line DAT_381, raw data. (A) full GPR line. (B) excerpt of line, white box. (C) Interpretation of (B). See Text for description of units and Figure 1 for location of survey line. U1 is Unit 1; U3 is Unit 3.

FACIES4 – was observed in the southeastern portion of the survey transect. Where present, the unit was characterized by extremely high intensity reflections. The increase in intensity was not restricted to a specific package of reflections, rather as an overprint over existing GPR stratigraphic features. FACIES4 is a secondary feature and the GPR signature originates from post-depositional alteration of the sediments.

FACIES5 – was observed on the southeastern section of the survey transect. The character of the upper bounding surface truncated reflections below. Internal reflections were characterized by parallel to subparallel, wavy and slightly sigmoid clinoforms. Minor internal truncation surfaces were recognized. FACIES5 was recognized at depth in the northwestern portions of the profile and shallower in areas where FACIES3 was absent.

Each of the facies were interpreted for depositional environment, processes and evidence for post depositional alteration (Figures 2 and 3).

UNIT1 – Anthropogenic Unit – FACIES1 exhibits the high-intensity reflectors at the surface and in the shallow sub surface. The facies was observed throughout the entire survey with a varied thickness. GPR lines were acquired on unimproved or slightly improved sand roads that experience various degrees of vehicle traffic. FACIES1 with its high intensity, surface parallel reflections is indicative of overcompaction. Based on the geospatial association with roads and the character of the facies, FACIES1 is interpreted as UNIT1 – Anthropogenic Unit, primarily roads.

UNIT2 – Dune Sediments – FACIES2 was observed in areas where the surface topography away from the road was hummocky to vegetated low ridges. The low ridges are not consistently orientated with the present beach position. The wavy character coupled with the stratigraphic character are indicative of low relief aeolian deposits (van Dam *et al.*, 2003). UNIT2 contains a sub unit, UNIT2a that is interpreted as potential wetland deposits based on comparison of GPR signature to

previous work in the area (Gontz *et al.*, 2014; Gontz *et al.*, 2015; van Dam, *et al.*, 2003).

UNIT3 – Upper Beach System – FACIES3 was observed in the northwestern portion of the transect. The seaward-dipping sigmoid clinoforms coupled with minor internal truncation surfaces are indicative of beach ridge deposition (Switzer *et al.*, 2010; Gontz *et al.*, 2014). As the lower bounding surface of the facies is an unconformity related to transgression, it is proposed that the facies above relates to the regressive beach system formed during sea level fall from the mid-Holocene highstand as observed in other locations (Gontz *et al.*, 2014; Switzer, *et al.*, 2010; Barboza *et al.*, 2009).

UNIT4 – Coffee Rock – FACIES4 was observed discontinuously throughout the Moon Point-Happy Valley Road transect. The facies was present in the southeastern portion of the profile and absent in the northwestern portion of the profile. The character of FACIES4 observed is similar in geophysical stratigraphy and environment of occurrence to units observed on GPR and ground truthed on the North Island of New Zealand (van Dam *et al.*, 2003) and known occurrences in the area (Cox *et al.*, 2000).

UNIT5 – Lower Beach System – FACIES5 was observed throughout nearly the entire transect. It was absent only in areas where saline ground water intrusion prevented penetration to depth. The internal character of the facies suggests that FACIES5 is a former beach system. The sigmoid clinoforms with minor truncation surfaces are similar to those found stratigraphically higher in FACIES3. A similar unit has been recognized at other locations in Australia (Gontz *et al.*, 2014; Switzer *et al.*, 2010; Barboza *et al.*, 2009). Based on the internal character, geographic position and stratigraphic location, FACIES5 is interpreted as UNIT5 – lower beach system.

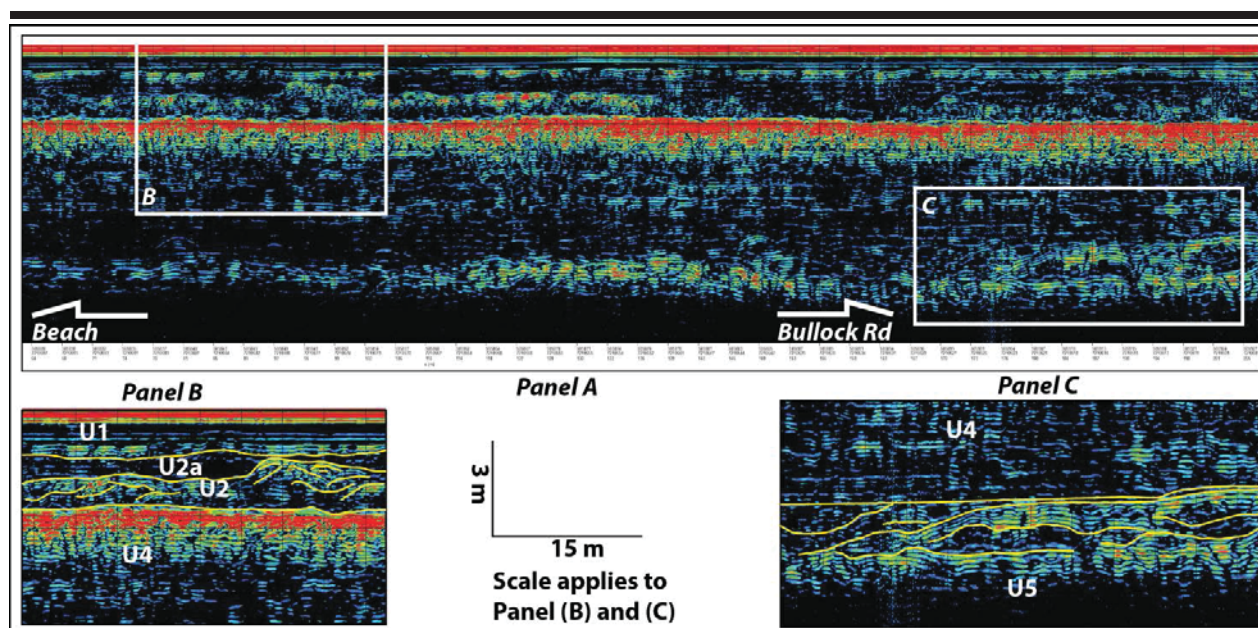


Figure 3. (A) Ground penetrating radar line DAT_385, raw data. (B) Interpreted of excerpt. (C) Interpretation of excerpt. Units are described in the text. See Figure 1 for location of survey line. U1 is Unit1; U2 is Unit 2; U2a is Unit 2a; U3 is Unit 3; U4 is Unit 4; U5 is Unit 5.

DISCUSSION

The progression of units from the present coast towards the southeast exhibits a pattern that is indicative of a regressive coastal plain (Gontz *et al.*, 2014). Moving further away from the coast to the southeast, the sequence transitions from one that is beach ridge deposition over a transgressive unconformity (Gontz *et al.*, 2013) with a lower beach ridge system beneath the unconformity to a less-clear dune sequence over coffee rock with indications of a beach ridge system below the coffee rock (Figure 4).

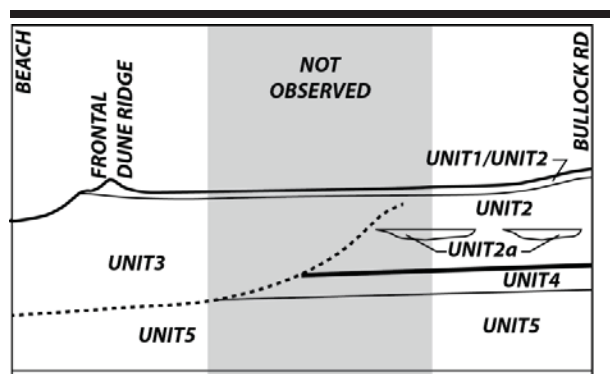


Figure 4. Conceptual model of the stratigraphic architecture from the present beach along the Moon Point Happy Valley Road to the Bullock Road intersection. See Figure 1 for location. Not to Scale

The patterns observed in UNIT3 and to some degree in UNIT5 exhibit similarities to other beach systems worldwide that have been correlated to periods of storm erosion and beach

recovery (Dougherty, 2013). Previous work (van Heteren, *et al.*, 1998) suggest that sea level elevations can be extracted from the changes in reflector morphology.

Similar work on North Stradbroke Island shows a similar pattern of low dunes capping a prograding beach ridge system over a transgressive unconformity with a lower beach ridge system underlying the sequence (Gontz *et al.*, 2014). The Moon Point sequence contains a unit not observed in other locations that has been interpreted as “coffee rock”. Coffee rock is a dark brown to black lightly cemented sandstone. Cementation is through organic compounds (Van Dam *et al.*, 2003). It is a barrier to shallow hand coring and has been encountered during coring in the pattern fens of Moon Point (Moss *et al.* in press). The GPR observations at Moon Point suggest the coffee rock layer ~ 1.5-2 m thick and cuts across the regional stratigraphic sequence. This supports previous research that suggests the deposition of organic compound to cement the layer is a result of downward migration of pore fluids and leaching from layers above or through long-term groundwater flow (Cox *et al.*, 2000). The GPR clearly shows reflectors crossing the boundaries of the high-intensity coffee rock (UNIT4; FACIES4). In Northern Queensland, deposits of coffee rock have been dated at 48,000 ybp based on roots contained within the deposit (Pye, 1982). The survey did not observe the northwestern edge of UNIT4 due to a large saline wetland complex. If the age of the Fraser Island coffee rock correlates with those in Northern Queensland, then the northwestern edge of the deposit may correlate with the location of the mid-Holocene highstand.

CONCLUSIONS

The GPR survey presented clearly shows several stratigraphic packages. These are interpreted as relating to present and former coastal systems. The stratigraphic relationships observed suggest that the following units exist:

1. An anthropogenically altered unit;
2. Present-day transgressive beach system;
3. Mid-to-Late Holocene regressive beach system;
4. Early-to-Mid Holocene transgressive beach system;
5. Buried wetlands;
6. Coffee rock; and
7. Late Pleistocene regressive beach system

Presently, dates are unavailable to correlate the stratigraphic packages and sequences across the Great Sandy region. However, this work presents the first step in understanding the dynamics of the system and how it has changed and evolved during the Late Quaternary. Work is ongoing to develop chronologies associated with the GPR stratigraphy, extract climate proxies from preserved coastal systems and reconstruct the palaeogeography.

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