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A Review of Coastal Dunefield Evolution in Southeastern Queensland

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ABSTRACT

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The Southern Queensland subtropical coastline represents a major depositional system containing 3 of the largest sand islands in the world. The surface of these sand masses comprises foredune ridges and predominantly large transgressive dunefields, deposited episodically during the Quaternary. The chronological sequence of these dunefield phases, however, is still poorly understood. This paper summarizes the information available regarding dunefield transgression events on the southern coast of Queensland and indicates that both marine and climate effects are important controlling factors for dunefield evolution but that an understanding of the relative thresholds of each factor as the main trigger of dune emplacement phases remains a challenge .

ADDITIONAL INDEX WORDS: *Dune emplacement phases, climate, sea level changes.*

INTRODUCTION

The Southern Queensland (QLD) subtropical coastline represents a major depositional system containing 3 of the largest sand islands in the world: Fraser, North Stradbroke and Moreton Islands as well as the mainland attached Cooloola sand mass (Figure 1). This review paper will focus on these large sand masses, built by siliceous deposition through processes that have been operating for at least 750,000 years (Tejan-Kella *et al.*, 1990).

The surface of these sand masses comprises foredune ridges and predominantly large transgressive dunefields as a result of substantial sediment supply and continual exposure to the prevailing onshore southeasterly winds. The dunefields were deposited episodically during the Quaternary (Ward, 1978) and contain overlapping phases of parabolic dune systems (Figure 1) (Thompson, 1981) and some transgressive sand waves. The initiation of each individual phase has been the subject of debate, attributed either to sea level lowstands (Ward, 1978) or to successive Quaternary marine transgressions (Thompson, 1981). In fact, the literature debate on whether marine (sea level) factors or climate are the main triggers for dunefield initiation is common to other regions around Australia and elsewhere (Lees, 2006; Young *et al.*, 1993).

This paper aims to summarize the information available regarding dunefield transgression events on the southern coast of QLD and indicate possible main triggers of initiation. This stretch of coastline is particularly interesting as it contains one of the longest records of dunefield evolution in the world, representing an ideal site where models of long-term dunefield evolution can be tested (Cooper, 1958; Pye and Bowman, 1984; Thom, 1978; Young *et al.*, 1993).

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Soil development and age inferences

The parabolic systems in the study area have some of the deepest and most highly developed podosols (podzols) in the

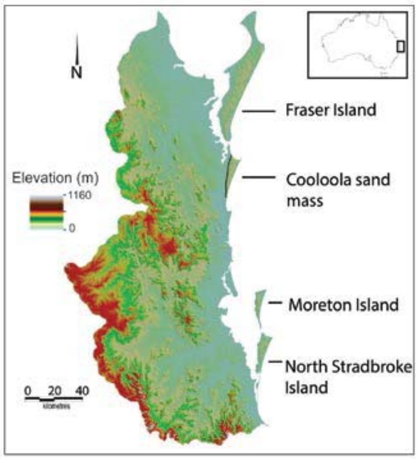

Figure 1. Study area with the sand masses discussed in the text. State of Queensland (Department of Environment and Resource Management) 2010. Data from Commonwealth of Australia (Geoscience Australia) 2009 used in creating this dataset provided under Creative Commons Australia - Attribution licence. Updated data available at http://dds.information.qld.gov.au/dds

world, due to the long history of the dunefields, favourable climatic conditions, the high porosity of the sediments and absence of a water table to considerable depths (Thompson, 1981). Profile development or depth of A1 and A2 horizons to the firm, iron-humus rich Bhir horizon can be as much as 30 metres in the oldest dunes (Thompson, 1981).

Thompson (1981) presents a chronological sequence of dune systems 1 to 6 in Cooloola according to their degree of erosion and podosol profile development, with no absolute ages inferred to those systems. The oldest dune systems (5 and 6) have the deepest podosols (~11m and up to 20m, respectively) and have been subjected to deep water-related erosion, losing their original parabolic morphology (Thompson, 1981). Thompson (1981) suggests that they are likely of Pleistocene age, including system 4 (>40,000 yr BP). The three youngest parabolic dune systems are likely of Holocene age (Thompson, 1981), formed during the last 6 ka after sea level reached its present elevation (Thom *et al.*, 1978), from their intact dune morphologies and limited soil profile development (<1.2m). Sequences of podosols examined in Cooloola have been correlated to sand units in Fraser, Moreton and North Stradbroke Islands (Thompson, 1981). For example, Thompson's system 3 in Cooloola and the dunes at Triangle Cliff in Fraser Island have been correlated due to similarities in surface morphology, stratigraphy and degree of soil development (Ward, 1985). The absolute age of Triangle Cliff, the largest sand unit in Fraser Island is yet to be accurately determined as indeed are the ages of most dune units in SE QLD.

EPISODES OF DUNE BUILDING IN SOUTHEAST QLD

Pickett *et al.* (1989) obtained a mean ^{230}Th/^{234}U date for 3 well preserved coral species assemblages in North Stradbroke Island of ~124 ka BP, belonging to the marine transgression in isotope stage 5e. The good preservation of the coral specimens indicate that they were buried rapidly *in situ* by an advancing, contemporaneous parabolic dune system during a period of higher sea level (between +1 and +3m). This dune is associated with Thompson's dune system 5 by Tejan-Kella *et al.* (1990) and not associated with low sea levels or very dry climate conditions according to Pickett *et al.* (1989) and Tejan-Kella *et al.* (1990). Tejan-Kella *et al.* (1990) extend this interpretation to their Warrawonga sample (TL age of 90 ±10 ka BP). However, Ward (1985) questioned these coral ages (which were revised by Pickett *et al.*, 1989), and consequently the age of the related dune system, on the basis that their use of a closed-system model does not approach the reality of coral system environments.

Radiocarbon dates from the Southeastern QLD dunefields are scarce and of questionable reliability. Its long history of Quaternary evolution, with the bulk of the sandmasses built around the mid-Pleistocene (Brooke *et al.*, 2015) makes the radiocarbon technique potentially useful to date only the very last periods of deposition. The first absolute dates for the area (Cooloola and North Stradbroke Island) were obtained in the early 1990's by Tejan-Kella *et al.* (1990), who found that the TL dates agreed with the relative chronological sequence from the soil evidence of Thompson (1981), except for the youngest sample in Kings Bore that yielded a Pleistocene age of 19±2 (later corrected to 11 ka) in a system that has morphological, stratigraphic and pedological characteristics of recent deposit (500 years was suggested by Tejan-Kella *et al.*, 1990 (Figure 2). Tejan-Kella *et al.* (1990) suggested that the sample must not have completely zeroed in this youngest deposit, which lead to erroneous TL determinations. Figure 2 displays the TL dates available for the study area (Brooke *et al.*, 2015; Tejan-Kella *et al.*, 1990).

The initiation of sand accumulation and dunefield development in Southeastern QLD has also been a matter of debate. It has been attributed to periods of low sea level by Ward (1978) who argued that accumulations occurred during low stands over the Quaternary from aeolian reworking of sediments exposed on the continental shelf. This theory is problematic since Fraser Island would be up to 50km inland at low sea stands which would make coastal dune building rather questionable (Cook, 1986). Schofield (1975) has associated dunefield activation phases to periods of marine regression and greater exposure of continental shelf providing sediments for onshore winds to form transgressive dunefields in the South Kaipara Barrier, New Zealand. This model might be accepted in areas where vegetation growth is limited and onshore winds are strong (Roy and Thom, 1981). However, even if during the Last Glacial Maximum (LGM), westerly winds were stronger, such as is inferred in New South Wales (NSW) (Thom *et al.*, 1994), coastal pioneer vegetation would have colonised the relict beaches as sea level fell just as it does now under beach progradational conditions (Hesp, 2002). Even in the NSW example above, the dunes have a continental origin and were derived from reworked interglacial coastal dunes.

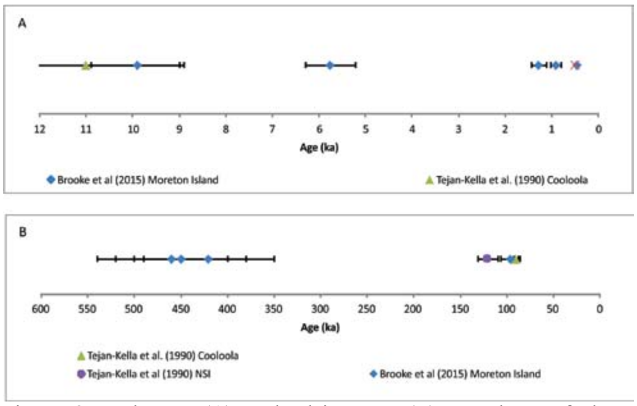

Figure 2. Holocene (A) and Pleistocene (B) TL dates of dune emplacement available for Southeastern QLD. Horizontal dark lines refer to the uncertainty associated with each date.

In contrast, initiation of sand accumulation and dunefield development in Southeastern QLD has also been attributed to periods of sea level rise. Thompson (1981) suggests that the siliceous sands that dominate the QLD coastline were derived from the shoreface during periods of marine transgression during the Quaternary and accumulated during periods of highstand when sea level returned to present (or near present) elevations during successive interglacials.

Cooper (1958)'s work on the Oregon and Washington (USA) dunefields has suggested that phases of dunefield instability are associated with marine transgression, which was firstly expanded to Australia by Thom (1978), Pye (1984), Pye and Bowman (1984). The so-called known Cooper-Thom model of sea level rise as a main trigger for dunefield activation in Australia and climate as a supporting factor has since then been advocated by many authors in more recent publications (Lees, 2006) but criticized by others (Young *et al.*, 1993), who support the idea that dune activation phases were brought about primarily by climatic factors. We explore possible climate and/or marine triggers for dunefield activation in Southeastern QLD in the next section.

QUATERNARY CLIMATE AND SEA LEVEL CHANGES

There are very few luminescence dates for these systems (Figure 2) and the correlation between dune phases and the palynological and climate record can be challenging. However, it has been assumed that moisture has been always enough to support vegetation even during the Last Glacial Maximum (LGM) in this region. Thompson (1981) and others argue that in Cooloola there is no signature of significantly drier climate conditions during the last glaciation, beyond the threshold for plant colonization. These authors base this conclusion on the fact that the dune systems have preserved their parabolic shape since then and that there is no evidence of desert-type dune systems. This assumption contrasts with the well understood concept that parabolic shapes can evolve from linear, barchan desert-type features as vegetation grows (Tsoar and Blumberg, 2002).

More recently, Moss *et al.* (2013) suggests that rainforest was present on the dunes at North Stradbroke at the LGM. In contrast, work from Fraser Island (Longmore and Heijnis, 1999) suggests that rainforest is absent during the LGM but there is no suggestion that the dunes are devegetated at that time. Although dates that indicate dunefield emplacement during the LGM are absent from the record so far, the presence of vegetation does not eliminate the possibility of dune emplacement phases at this time, as large parabolics such as these in Southeastern QLD are capable of advancing inland regardless of dense forest cover (Pye, 1982). A more likely reason for their absence is the 30-50 km distance to the nearest coast at the LGM.

In the following, only the available luminescence dates obtained thus far for the Southeastern QLD landmasses will be discussed (Figure 2). We group ages from Moreton Island, North Stradbroke and Cooloola as representative for this entire section of the coast (Ward, 2006), although the absolute chronological sequence and correlation with the virtually undated Fraser Island is yet to be tested.

Mid-to-Late Pleistocene: Figure 2B shows a cluster of TL dates around the mid-to-late Pleistocene (between ~420 and ~460 ka BP) (Brooke *et al.*, 2015; Tejan-Kella *et al.*, 1990). It could be that dunefield emplacement during the mid-to-late Pleistocene may have well been a result of a climate trigger (Figure 3A), although Longmore and Heijnis (1999) infer from pollen, chemistry and charcoal analysis that water levels at the Old Lake Coomboo Depression in Fraser Island were high at ca 600 ka and intermediate after ca 350 ka. Perhaps moisture was sufficient to keep the lake levels and some vegetation cover however nothing is known about paleo wind direction and strength in Southeastern QLD during the mid-late Pleistocene. Stronger winds during a cold, glacial period could have been enough to trigger sand mobility, limiting the establishment of vegetation and promoting dunefield activity (Tsoar and Blumberg, 2002). As Shulmeister (1992) reported, there is no direct evidence for aridity triggering dune activation in any northern Australian coastal dunefields and the likelihood of true aridity on this coastline is remote. Alternatively, dunes may have been formed as source bordering dunes derived from river margins crossing the exposed shelf. The Mary River is a good candidate for this, but it is questionable as to whether the regionally extensive older sand units (e.g. the Yankee Jack and Cooloola phases) could be triggered by sources that are perpendicular to the coast and the dunefield alignment.

Last Interglacial: Another cluster of dates surrounds the last interglacial (90 to 120 ka BP, isotope stages 5c to 5e). (Figures 2B and 3A). Tejan-Kella *et al.* (1990) assume that these dune phases in SE QLD are not associated with periods of lower sea level and drier climate and we reinforce this model by supporting Brooke *et al.* (2015) theory that dune building events at this time could have been associated with "intermediate" sea levels, which persisted during stage 5. Longmore (1997) suggests low fire incidences during this period in association with the recovery of rainforest and a temporary increase in lake levels, indicating humid conditions during this broad interval.

Last Glacial Maximum: Longmore and Heijnis (1999) affirm that the last glacial maximum (LGM) was drier than previous glacial cycles in the Fraser Island region. Dust tracing indicates that the finest aeolian sediment fractions at Tortoise Lagoon on North Stradbroke Island were derived from the Murray Darling Basin. This area lies to the Southwest of the region and suggests the maintenance of winter westerlies over this region during the LGM (e.g. Petherick *et al.*, 2008). Interestingly, absolute dates of aeolian activity during the LGM (22-20 ka) are not present in the Southeastern QLD record. Dust in the Native Companion Lagoon record is mainly provenanced from continental sources rather than local (Petherick *et al.*, 2008). More diagnostic evidence is required to claim dune emplacement phases during the LGM perhaps associated with the expansion of the Simpson Desert (Thom *et al.*, 1994).

Early Holocene: Two TL samples (Brooke *et al.*, 2015; Tejan-Kella, *et al.*, 1990; Figure 2A) cluster around early Holocene (11 to 8.5 ka BP). Cook (1986) summarizes coastal dune building events in eastern Australia and suggests a major widespread period of transgressive dune instability between 9k and 7k years ago. The North Stradbroke Island climate record suggests low aeolian sedimentation and decreased aridity (Petherick *et al.*, 2008). A marine transgression cause must also be considered as sea level was rising rapidly during the last marine transgression.

Mid-to-Late Holocene: The two dates (5.75 ka BP and 3.1 ka BP, Figure 2A) indicate dune emplacement during a period of climatic deterioration according to Petherick *et al.* (2008), represented by initiation of a dry phase in subtropical Australia (Donders *et al.*., 2007) and highly variable climate conditions related to the onset of El Niño Southern Oscillation (ENSO) conditions (Shulmeister and Lees, 1995). Sea level was at a highstand at ~6 ka following the last marine transgression and falling slightly from ~2 ka (Lewis *et al.*, 2013 and Figure 3B). Here dunefield emplacement could have been promoted by increased onshore sediment supply during the last marine transgression combined with a drier, windier climate.

Late Holocene: The sea level record shows a smooth decline from ~+1.0 metres to present from about 2 ka BP (Figure 3B). Dune emplacement happened at about 0.9 and 1.28 ka B.P (Figure 2A). The climate record points to more modern conditions, e.g., highly variable within an aridifying trend after ~3 ka BP (Donders *et al.*, 2006; Shulmeister and Lees, 1995). McGowan *et al.* (2008) affirms that during the last 1500 years, the aeolian sedimentation record in North Companion Lagoon has been at a constant rate of about 0.7 g m -2 yr-1.

Hayne and Chappell (2001) detected storm deposits in northern QLD over the last 5000 years, including deposits dated at ~500 and ~1000 yrs BP. Records of paleo-storms are absent in Xoutheastern QLD, but they likely exist (Gontz *et al.*, 2015) and should be tested against periods of dune emplacement over the late Holocene.

The more recent dunefield emplacement phases have been attributed to aboriginal firing and European colonization, which has been dismissed by Cook (1986) and Levin (2011) as possible causes for major dunefield activity. Most recently, although sea level is recorded to be rising at a rate of about 0.7 mm/year between 1964 to 2012 (BOM, 2013, data from Bundaberg), Levin (2011) has demonstrated that sand blows in Fraser have been largely recolonized by vegetation. He inferred that this was due to a decrease in storm incidence related to a shift in the IPO (Interdecadal Pacific Oscillation).

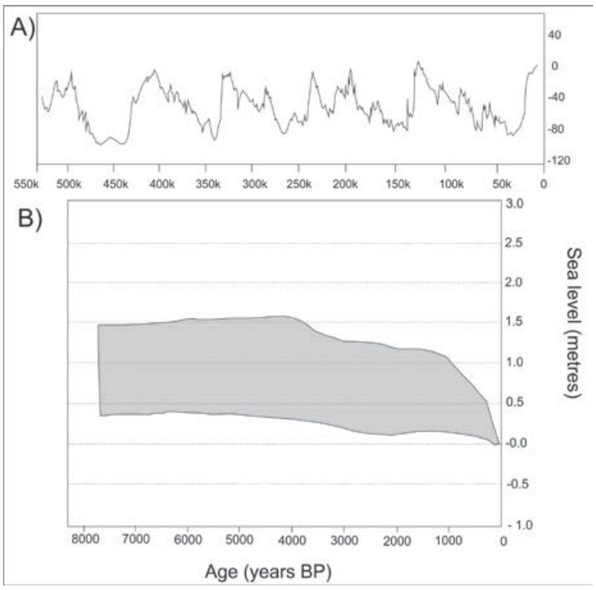

Figure 3. (A) Sea level curve for the last 550k (mid-late Pleistocene) modified from Rohling *et al.* (2009) and (B) sea level envelope for Northern QLD (modified from Lewis *et al.* (2013).

CONCLUSIONS

The southern coast of QLD contains one of the most extensive records of Quaternary dunefield evolution in the world, and is an excellent area to examine the relative contributions of sea level change and climate to phases of dunefield activity. The chronological sequence of these dunefield phases, however, is still largely unknown. From the rare luminescence dates available in the area, it is possible to identify dune building phases associated with “intermediate” and high sea levels. In contrast, during the LGM, coastal dunefield development on modern Fraser Island is unlikely, but broader regional climate conditions were favourable for long-distance aeolian dust transport and sedimentation. Dune phases dated to the mid-to-late Holocene are possibly associated with variable climate after ~5 ka that probably reflects the widely recognised onset of an ENSO like regime with associated enhanced drought risks. At shorter timescales individual tropical storms play an important role in dune activation. Most recently, many sandblows (actually parabolic dunes) on Fraser Island are being re-vegetated, associated with a decrease in storm frequency and intensity due to the shift to cooler coastal waters under the IPO. It is evident that both marine and climate effects are important controlling factors for dunefield evolution. An understanding of the relative thresholds of each factor and/or what condition causes one or the other to prevail as the main trigger of dune emplacement phases remains a challenge, but could potentially be resolved by further studies in the SE QLD coastal deposits.

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