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Abstract

Prehistoric depositional signatures for large-scale washover involving marine inundation events such as storm and tsunami have been the subject of considerable research over the last 15 years. Much of this research has focused on the identification of sand sheets in back-barrier environments as depositional records for extreme washover events. All these deposits must have a sediment source, and by their nature, the most likely source of sediment for washover into back-barrier environments is the barrier itself. This study identifies an erosional signature for large-scale washover from a small coastal barrier on the southeast Australian coast. A distinct lense of marine sand, up to 90 cm thick, is confined vertically by peat and is found in the upper fill of a closed freshwater back-barrier lagoon sequence. This sand lense is attributed to a large-scale washover event that occurred at approximately 1500 AD, possibly by tsunami. The hypothesis for this study was that any event that breached the dune system must have caused considerable geomorphic change to the dunes and hence may leave an erosional signature of the event. Ground penetrating radar transects of the system show an erosional contact between a series of truncated pre-event dunes and several small overlying post-event dunes. This study outlines a relatively simple non-invasive method for the identification of an erosional signature for prehistoric largescale washover by storm surge, exceptionally large waves or Tsunami.

Keywords

Investigation, large, scale, washover, small, barrier, system, southeast, Australian, coast, using, ground, penetrating, radar, GeoQUEST

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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An erosional signature of large-scale washover identified using ground penetrating radar on a small barrier system from the southeast Australian coast

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Abstract

Prehistoric depositional signatures for large-scale washover involving marine inundation events such as storm and tsunami have been the subject of considerable research over the last 15 years. Much of this research has focused on the identification of sand sheets in back-barrier environments as depositional records for extreme washover events. All these deposits must have a sediment source, and by their nature, the most likely source of sediment for washover into back-barrier environments is the barrier itself. This study identifies an erosional signature for large-scale washover from a small coastal barrier on the southeast Australian coast. A distinct lense of marine sand, up to 90 cm thick, is confined vertically by peat and is found in the upper fill of a closed freshwater back-barrier lagoon sequence. This sand lense is attributed to a large-scale washover event that occurred at approximately 1500 AD, possibly by tsunami. The hypothesis for this study was that any event that breached the dune system must have caused considerable geomorphic change to the dunes and hence may leave an erosional signature of the event. Ground penetrating radar transects of the system show an erosional contact between a series of truncated pre-event dunes and several small overlying post-event dunes. This study outlines a relatively simple non-invasive method for the identification of an erosional signature for prehistoric large- scale washover by storm surge, exceptionally large waves or tsunami.

Key words: Ground-penetrating radar, washover, erosion, tsunami, Australia

Introduction

The ground penetrating radar (GPR) technique allows the operator to image, locate and identify changes in electrical and magnetic properties in the ground through the use of electromagnetic wave propagation and scattering (Leatherman, 1987). The technique is particularly applicable to sandy sediments and is, therefore, a desirable tool to interpret and reconstruct dune systems including those of coastal barriers (Leatherman, 1987; Jol and Smith, 1991; Bristow, 1995; Jol *et al.,* 1996, 2003; Van Heteren *et al.*, 1996, 1998; Bristow *et al.*, 2000; Neal and Roberts, 2000; Neal, 2004). Using the propagation and subsequent reflection of pulsed high frequency electromagnetic energy, the GPR method can provide high resolution (down to em), near continuous profiles of many coarser-grained deposits to depths of up to 60 m (Jol *et al.*, 2003).

The GPR profiles complement a coring program to investigate the occurrence of a thin laterally extensive sand sheet found in the upper fill of the back-barrier lagoon sequence. Studies of storm deposits from back barrier environments (e.g. Leatherman and Williams, 1977; Liu and Fearn, 1993; Sedgwick and Davis, 2002) and tsunami sand sheets (Minoura and Nakaya, 1991; Minoura *et al.*, 1994; Dawson, 1994; Dawson, 1996; Hindson *et al.*, 1996; Dawson and Shi, 2000; Clague *et al.*, 2000) suggest that high-energy washover events from both large storm surges and tsunami can deposit fine sediments behind sandy barriers when velocities of the flood current drop dramatically after breaching the barrier system (Dawson 1999; Zong and Tooley, 1999). Such events are often recorded in the geological record and stratigraphic investigations of back-barrier lagoons can often yield valuable information about modem and pre-historic washover events.

Studying storm surge deposits, Zong and Tooley (1999) suggested that reliable washover signatures can only be developed by using appropriate analytical techniques, including the analysis of particle-size distribution of the storm layers with respect to associated biogenic sequences (Delaney and Devoy, 1995), examination of lateral textural grading of washover deposits within horizontal laminae (Leatherman and Williams, 1977) and the identification of sand layers in lagoon cores (Liu and Fearn, 1993). Some investigations of storm deposits have focused on the internal stratigraphy of coastal dune systems (Jelgersma *et al.*, 1995) although back-barrier investigations dominate the literature (eg. Leatherman and Williams, 1977; Morton, 1978; Liu and Fearn, 1993;

Delaney and Devoy, 1995; Sedgwick and Davis, 2002). The focus of this study involves analysis of the geological record for an erosional signature within the dune system. One would expect that if the marine sand forming the sand sheet is the product of washover than the sandy barrier, would have experienced considerable erosion. Furthermore, it is reasonable to expect that such an event would have caused considerable geomorphic change to the barrier and that the likelihood of an erosional boundary occurring within the vertical stratigraphy of the dune is high, based on the basic assumption that barrier and indeed dune activity resumes soon after the washover event.

Study site

Killalea Lagoon lies on the southeast coast of Australia and is predominantly a freshwater swamp, being only rarely and temporarily inundated by storm conditions at its seaward margin (Fig. 1). The lagoon is enclosed between headlands of Permian volcanic bedrock and separated from the sea by a barrier beach and vegetated foredunes. The beach faces into the dominant southeast swell on the coast. A sequence of estuarine and back- barrier lagoonal clays occurs to depths of 25 m and records Quaternary sea level fluctuations in the small embayment. A Holocene barrier system onlaps the sequence to the south and is composed of clean beach and aeolian sand. The barrier is topped by a large accumulation of fine aeolian sand with a contemporary surface expression of a series of small well-vegetated transgressive foredune ridges. Water depths in the lagoon fluctuate throughout the year but are rarely more than 1 m. Samples taken from the organic-rich lagoon floor suggest that the major components are reed fragments including *Juncus* sp. and *Triglochin striata.* The most common identifiable remains within the lagoonal sediment are the reproductive bodies and fragments of freshwater algae (charophytes) and seeds, with rare ostracoda.

Holocene stratigraphy

Silty peat deposits with minor amounts of fine aeolian sand dominate the upper parts of the mid- to late- Holocene sedimentary lagoonal fill. A thin laterally extensive sand deposit in the upper embayment fill extends up to 450 m inland and rises to1.6 m AHD (Fig. 2a). Coring of the deposit suggests it is continuous and tapers landward. The deposit sharply overlies the upper part of the lagoonal sequence (Fig. 2b) and consists of fine- to medium -grained sand with some organic material dominated by fragments and rootlets of *Spinifex* grasses.

AMS radiocarbon and optically stimulated luminescence (OSL) dating of samples taken from the sandsheet (fig. 2c) and upper 2 em of the underlying peat places the age of the sand sheet at around 1400-1500 AD. In places the sand is overlain by accumulations of organic-rich silt that contain charophytes suggesting re- establishment of freshwater lagoon conditions. Microfauna!investigation identified a general lack of carbonate microfauna throughout the cores, most likely the result of dissolution due to the presence of organic acids associated with the freshwater lagoonal environment. Large populations of charophyte flora were identified in cores at various intervals throughout the upper fill. Charophyte remains were absent throughout the sand sheet deposit but occurred both above and below it.

Hypotheses considered for the deposition of the sand sheet are a higher Holocene sea-level, storms and tsunami. The silty organic nature of the overlying sediments along with the presence of charophytes *Chara australis* and *Chara fibrosa* suggest that the sand depositional event was short lived and lagoonal sedimentation resumed soon after deposition. The late Holocene age of the sand sheet along with the lack of associated beach deposits and evidence of wave scouring suggest that a higher sea level hypothesis is unlikely. This deposit is probably the result of a rapid high-energy oceanic inundation from the south or southeast. This project is part of a larger study of elevated sand sheets along the coast of New South Wales, Australia that are sedimentologically and spatially unique, occurring only in embayments that face southeast. This study aims to test the hypothesis that an erosional signature for such prehistoric large-scale washover events can be found in the seaward dunes of such embayments and can be located using ground penetrating radar.

GPR methods

The GPR profiles were collected using a Pulse Ekko FE 100 with 1000 volt transmitter and 100 MHz antennae spaced 1 m apart in perpendicular broadside configuration with a step size of 0.5 m. The GPR data was processed using Pulse Ekko software and processing includes dewow, an age gain of 100 and topographic correction. In addition, profile KGPR-2 has been migrated to collapse parabolic reflections from a wire fence at 60 m. Velocities have been determined from CMP surveys on the sand dunes and on the lagoon deposits. The velocity for the sand dunes is 0.15 $m.ns^{-1}$ with a corresponding velocity of 0.06 $m.ns^{-1}$ for the lagoon deposits.

Results

Based on the presentation format of Jol *et al.* (2003) GPR profiles and interpretation will be presented as follows; the horizontal scale of all profiles and schematic interpretations are presented as distance in metres, with two vertical scales for the GPR profile and one for the schematic. Two-way travel time (ns) appears as the first vertical scale (in italics) and secondly depth (m), based on the near-surface velocity of a radar pulse through the sediments closest to the profile. Air wave and ground wave arrivals are present in all profiles as the two uppermost continuous reflections, respectively, and should not be considered part of the stratigraphic data.

Three GPRprofiles were conducted for this study. The first (KGPR-1) was conducted at the landward extremity of the sand sheet in order to investigate the deposit with the aim of defining its extent and complementing the coring program, the second (KGPR-2) and third (KGPR-3) profiles aimed to investigate the contact between the lagoonal deposits, the washover sand and the Holocene dunes, with a working hypothesis that if the dunes were the source of the marine sand in the sand sheet could GPR identify any geomorphic signature for the modification of the system.

KGPR-1

The GPR profile (Fig. 3a) runs along the eastern edge of the lagoon to about 500 m inland. The location was selected to try and delimit the landward extend of the sand sheet which had been interfered from borehole data (Fig. 1). The profile shows limited depth of penetration down to around 3m with sub-parallel, sub-horizontal reflections above an irregular surface. The sub-horizontal reflections are interpreted to come from fine-grained, bedded lagoonal sediments overlying and infilling an eroded bedrock topography. This profile (Fig 4a) provides little information on the sand sheet but did assist in defining the depth to bedrock and indicated the dissected nature of the underlying bedrock basin in which the Quaternary sediment is deposited. Borehole data shows that the sand sheet lies very close to the surface and is only in the order of 40-80 em thick throughout the southern part of the transect before tapering off rapidly to its landward extremity about half way along the transect. The sandsheet is overlain in most places by less than 10 ern of organic-rich lagoonal sediment and could not be resolved because it has been obscured by the direct airwave and ground wave signal intrinsic to the methodology.

KGPR-2

The site of this profile was selected to investigate the seaward margin of the sand sheet and to target the interaction of the sand sheet, lagoonal sediments and dune system. The profile (Fig. 3b) shows two different reflection patterns. The northern part of the profile contains sub-horizontal reflections which pinch out towards the south, onlapping dipping reflections. The southern part of the profile has a low-angle reflection at the base overlain by tangential inclined reflections that downlap onto the low-angle reflection. The inclined reflections are truncated and overlain by a horizontal reflection. Above this there is a subhorizontal reflection and small discontinuous reflections within the gently undulating foredune topography. The lower low-angle reflection is interpreted to come from the top of an underlying Pleistocene barrier. The inclined tangential reflections which dip towards the north (inland) are interpreted as sets of cross-stratification from transgressive coastal dunes. The dunes are truncated by a second upper horizontal reflection interpreted to be an erosion surface formed during a large-scale washover event. This erosion surface can be correlated with a similar reflection on profile KGPR-3 (Fig. 3c). The erosion surfaces may be correlated with the sandsheet in the lagoon, however, the hyperbolae from the wire fence at 60 m partially obscure the critical stratigraphic contact.

KGPR3

This profile complements that of KGPR2 some 60 m to the east, away from the fence, and also shows the interaction of the lagoonal sediments and dune system. The GPR profile shows a low-angle inclined basal reflection overlain by tangential inclined reflections which are truncated. The low-angle inclined basal reflection is similar to the basal reflection in Fig. 3b, and is interpreted as the top of the underlying Pleistocene barrier. The inclined reflections are interpreted as sets of cross-stratification from transgressive dunes and the erosion surface that truncates the dunes appears to dip beneath lagoonal deposits at around 100 m along the profile (Fig. 3c). There is another shallow horizontal reflection in the upper part of the profile that represents a second erosional truncation that appears to correlate startigraphically with the laterally extensive sandsheet in the upper fill of the lagoon sequence.

Discussion

GPR profiles were used to investigate the sedimentary structure and contacts of the barrier and back-barrier lagoonal sequence of the Killalea barrier system. The project also aimed to investigate the occurrence of a large sandsheet in the upper fill of the back-barrier lagoonal sediments that extends at least 450 m into the embayment. Sedimentological data indicate that the source for the well-rounded predominantly quartz sand found in the sand sheet is the seaward barrier and corresponding offshore zone, as indicated by a mixed heavy mineral assemblage characteristic of barrier sediments with a component of inner shelf material characterised by immature platy minerals (Switzer *et al.*, in press). Grain size data and textural analysis show that a significant proportion of the sediments are well-rounded fine sand with pitted surfaces that may be of aeolian origin (Switzer *et al.*, 2004). It is hypothesized that the sediment was emplaced by large-scale washover in the late Holocene and that such an event would erode significant amounts of sand from the barrier. Subsequent post-washover geomorphic adjustments have resulted in the generation of new aeolian dunes and preserve an erosional sedimentary signature within the dunes. Sedimentological and geomorphic studies of dune systems from Europe (Jelgersma *et al.*, 1995) and the United States (Leatherman and Williams, 1977; Liu and Fearn, 1993; Sedgwick and Davis, 2002) suggest that it is often possible to identify both an erosional and depositional signature for a washover event. Anthony and Moller (2002) used GPR on dunes from the North Sea coast of Denmark to define a series of radar-facies and contacts complemented by a coring program. In many cases they indicated that aeolian dune activity was often truncated by washover deposition resulting in sharp contacts between high-angle dipping aeolian beds and low-angle to laminated storm deposits.

GPR profiles KGPR2 and KGPR3 both indicate a period of transgressive dune building that is truncated by an early washover that does not have a corresponding extensive sandsheet and is onlapped by lagoonal sediments. Overlying this sequence is a sequence of fine sands most likely to be the result of aeolian deposition that resulted in the formation of a series of small prograding dunes characterised by high angle prograded bedding surfaces. These dunes were eroded and modified in the late Holocene. A flat-lying prominent reflector in both GPR profiles separates two sequences of high angle bedding and is inferred to represent two separate periods of aeolian deposition separated by an erosional contact generated by one large scale washover event. The contact is identified as a flat-lying reflector that truncates the angled reflectors of the bedding planes from the dunes and corresponds to the presence of a large sand sheet in the back barrier fill.

Conclusions

Ground penetrating radar transects of a small barrier system identified a stratigraphically consistent erosional contact between a sequence of truncated pre-event dunes and several small overlying post-event dunes. This study outlines a relatively simple non-invasive method for the identification of an erosional signature for prehistoric large-scale over-wash by storm surge, exceptionally large waves or tsunami.

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Figure Captions

Figure 1.

Map showing the embayed southeast Australian coast and Killalea Lagoon. The lower map outlines the extent of the washover sheet, the morphology of the embayment and locates the Ground Penetrating Radar (GPR-X) transects along with drillhole and vibracore locations. Cross-section A-A^1, which is presented in Figure 2, is also identified.

Figure 2.

a) Cross-section A-A^1 showing a Pleistocene barrier lagoon sequence overlain by a Holocene lagoon system that has an anomalous marine sandsheet in its upper fill. Relative positions of the GPR transects are indicated. b) Photograph of the contact between the organic-rich peat of the lagoon sequence and the washover sandsheet. Dating of this peat is supported by OSL dating of the sandsheet suggesting the sand was deposited around 1400-1500 AD. c) AMS radiocarbon and OSL dating from peat samples immediately underlying the sand sheet. Although contaminated by modem carbon moving through the sequence the age is best indicated by the maximum age of the peat which indicates the event occurred approximately 500 years ago in both cases. OSL dating of the sediments of the sandsheet support the hypothesis that this is a young deposit.

Figure 3.

Ground Penetrating Radar transects a) KGPR-1 this transect had shallow penetration to bedrock and failed to identify with any clarity the sharp contact between the peat and sandsheet (Fig. 2b) observed in cores. Both KGPR-2 (b) and KGPR-3 (c) identified a truncating reflector that occurred above prograding Holocene dunes indicative of erosion by washover. The erosional reflector is then overlain by a series of irregular reflectors indicative of more aeolian dunes.

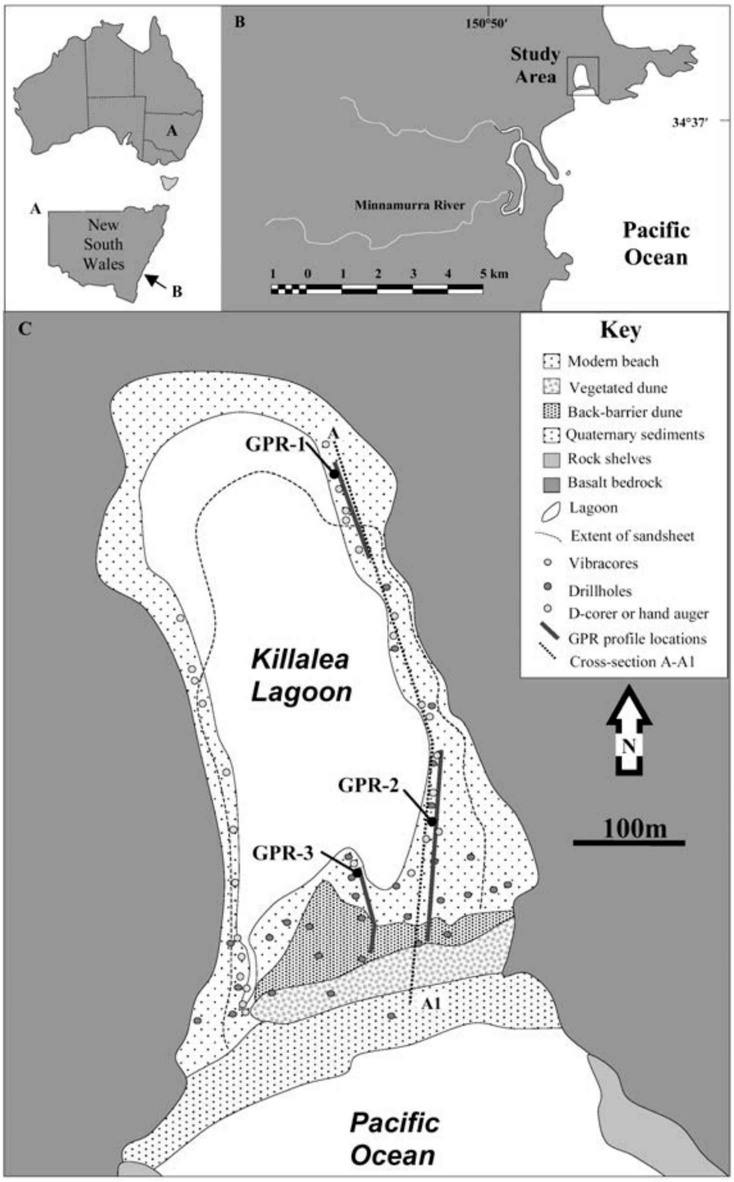
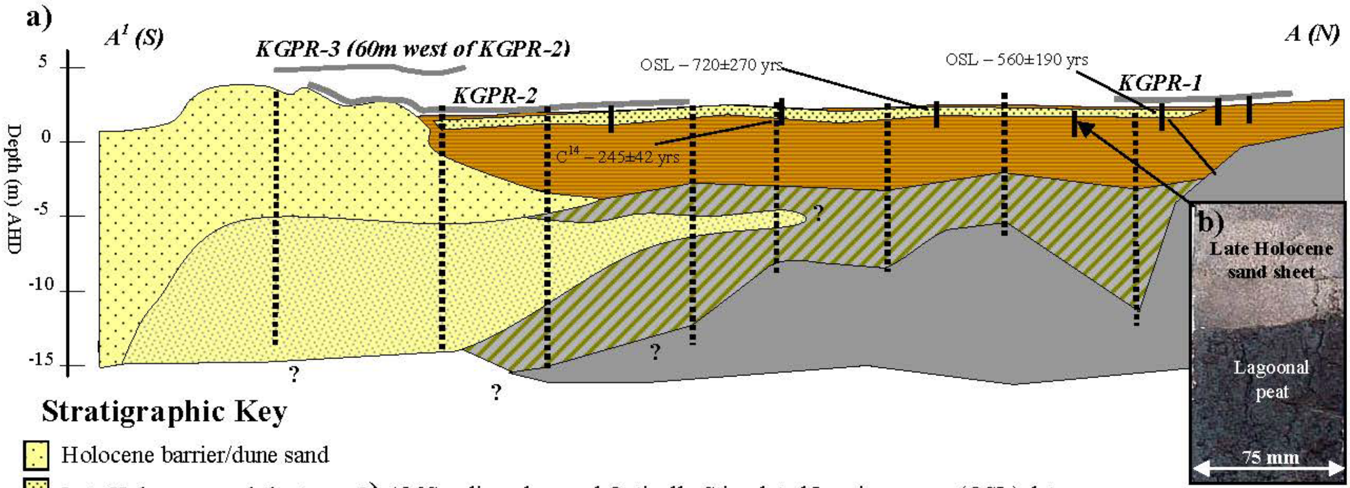

A
New
South
Wales
B
150°50′
Study
Area
34°37′
Minnamurra River
Pacific
Ocean
1 0 1 2 3 4 5 km
C
Key
Modern beach
Vegetated dune
Back-barrier dune
Quaternary sediments
Rock shelves
Basalt bedrock
Lagoon
Extent of sandsheet
Vibracores
Drillholes
D-corer or hand auger
GPR profile locations
Cross-section A-A1
GPR-1
GPR-2
GPR-3
A1
Killalea
Lagoon
N
100m
Pacific
Ocean

Fig. 1



c) AMS radiocarbon and Optically Stimulated Luminescence (OSL) dates

Sample (Depth AHD)	Specimen Number	Technique	Material dated	Unit	Sample notes	Age (yrs)
KVC3-0.30m	W13444	AMS ^{14}C	Bulk carbon on peat	Lower peat	Possible contamination by modern carbon from groundwater (Figure 3).	245±42
KVC6-0.20m	W13445	AMS ^{14}C	Bulk carbon on peat	Lower peat	Possible contamination by modern carbon from groundwater (Figure 3).	423±41
KVC3-1.2m	ASKOSL-1	OSL	Quartz sand	Sandsheet	Caesium^{137} suggests modern age	560±190
KVC5-1.0m	ASKOSL-2	OSL	Quartz sand	Sandsheet	(Minimum age model) Caesium^{137} suggests modern age	720±270

Fig. 2

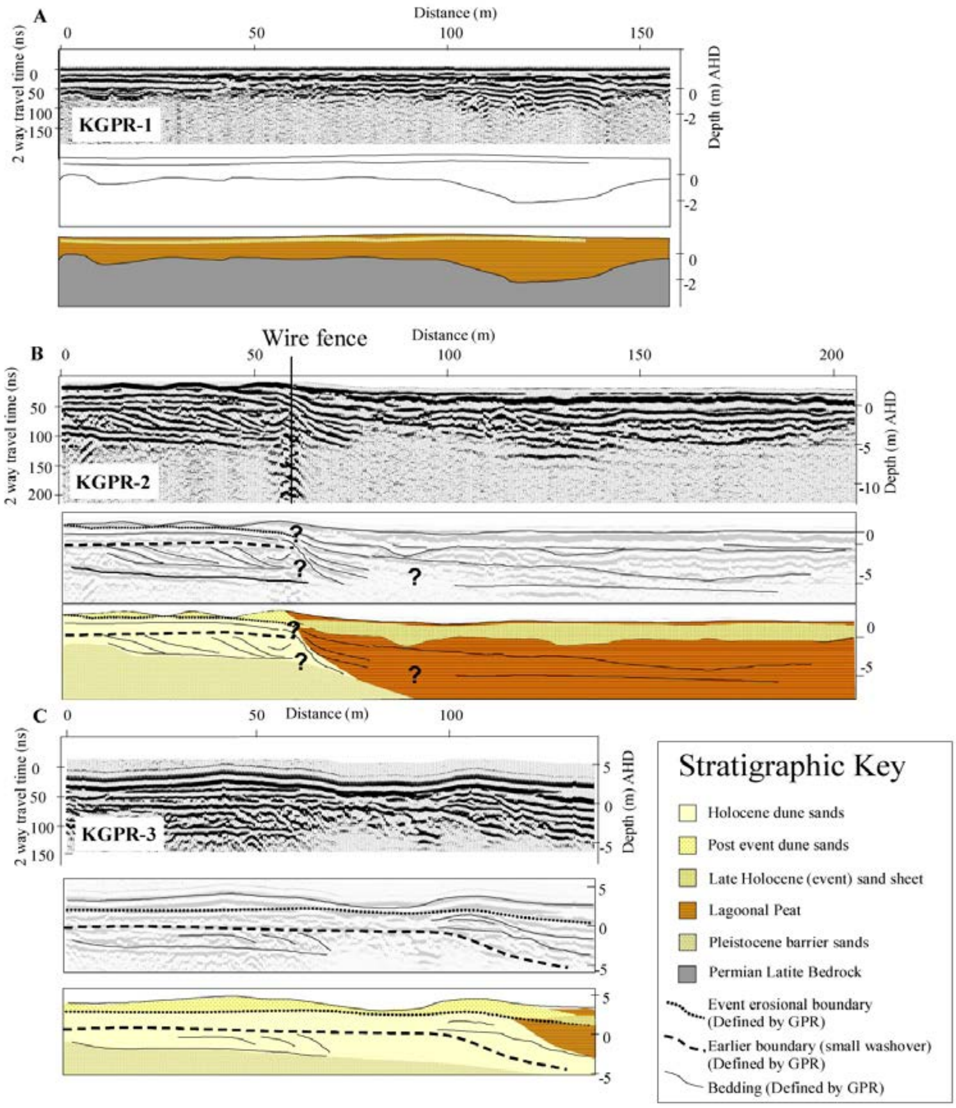

A
Distance (m)
KGPR-1
2 way travel time (ns)
Depth (m) AHD
B
Wire fence
KGPR-2
C
KGPR-3
Stratigraphic Key
Holocene dune sands
Post event dune sands
Late Holocene (event) sand sheet
Lagoonal Peat
Pleistocene barrier sands
Permian Latite Bedrock
Event erosional boundary (Defined by GPR)
Earlier boundary (small washover) (Defined by GPR)
Bedding (Defined by GPR)

Fig. 3