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Ground Penetrating Radar Investigation of Blueys and Boomerang Beaches

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Ground Penetrating Radar Investigation of Blueys and Boomerang Beaches

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Synopsis: **A Ground Penetrating Radar (GPR) investigation was conducted at Blueys and Boomerang Beaches, on the mid-north coast of NSW to investigate the coastal geology of the area. The primary aim of the study was to identify the presence and depth to bedrock within the previously defined erosion and recession hazard zone. A secondary aim was to locate the presence of buried erosion escarpments and comment on other coastal sedimentary features of interest. Careful processing and interpretation of the GPR data, coupled with geomorphic interpretation of the landscape provided new insight into the geological composition of the near shore zone. Recommendations were made to update the existing erosion and recession coastal hazard lines based on the outcomes of the GPR investigation.**

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Executive Summary

A Ground Penetrating Radar (GPR) investigation was conducted at Blueys and Boomerang Beaches on the NSW mid-north coast, to clarify a few unknowns coming out of the recent coastal hazard and processes definition study (WorleyParsons, 2011). The overall objective of the study was to investigate the coastal geological system, with the main aim being to identify the presence and depth to bedrock within the coastal zone. This information was then used to determine which shoreline locations are vulnerable to wave erosion and recession, and which are stable (i.e. resistant to erosion). The secondary aim of the study was to identify sedimentary features of interest, such as the location of buried erosion escarpments and buried boulder beach deposits.

A range of GPR systems and antennas were applied across the coastal zone in a series of transects that intersected one another and surveyed areas of known geology (i.e. existing borehole data; PWD, 1985). Multiple antenna frequencies were applied to maximise the likely outcomes of the survey, including a 50, 100 and 250 MHz antennas. A series of advanced signal processing techniques were applied to enhance the GPR data. The final processed radar profiles were interpreted with line drawings and correlated with the available geological borehole information. Features of interest identified include:

- Bedrock – sediment interface at southern Boomerang Beach and northern Blueys Beach;
- Various beach and dune reflections, including buried boulder beach deposit at southern Boomerang Beach; and
- Old erosion escarpments at both beaches.

Expert geomorphic interpretation of the Blueys and Boomerang Beaches coastal landforms was also conducted as part of this study, based on field observations and analysis of the available LiDAR digital elevation model and aerial photography. Combined, the interpreted GPR profile data and geomorphic interpretation of the landscape provided insight into the coastal geological system. As expected, the middle sections of Blueys and Boomerang Beaches were found to comprise erodible foreshore sediments. Towards Boomerang Point, these sediments were found to abut moderately sloping bedrock surfaces interpreted as relic coastal cliffs/slopes (i.e. a buried bedrock bluff) on both the Blueys Beach and Boomerang Beach side of the point. In these two areas, the existing hazard lines do not extend the entire length of the erodible shoreline and should be extended adjoin with the Boomerang Point bedrock interfaces identified in the GPR profiles.

In the case of far northern Boomerang Beach, no GPR data was collected from the barrier dune due to inaccessible ground conditions. However, interpretation of the landscape suggests that the buried bedrock slopes the adjoin Charlotte Head continue onshore in line with the adjacent bedrock cliffs (and local structure of underlying bedrock geology, both which trend to the northwest). As such, the alongshore extent of the hazard lines in this location are deemed to be appropriate. These lines should however be tied into the bedrock geology.

At southern Blueys Beach, the GPR results indicate the alongshore substrate varies from dune sediments south of the creek, to highly weathered (and erodible) bedrock slopes at the base of the Blueys Head and then stable (erosion resistant) bedrock substrate in the far corner of the beach. Surface geological investigations and geomorphic interpretation agree with this GPR interpretation. As such, the existing hazard lines should be removed from the areas identified as resistant to erosion at southern Blueys Beach.

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1 Introduction

1.1 Background

A coastal processes and hazard definition study was conducted for Blueys and Boomerang Beaches by WorleyParsons in 2011. As part of that previous assessment, the coastal erosion and recession hazard was estimated using an industry standard coastal engineering approach which assumes the shoreline and backshore landforms are comprised of erodible sediments. The coastal geological system is however more complex than this, as indicated by existing geological borehole information (PWD, 1985) and field evidence. As such, community groups have raised their concerns about the validity of the coastal hazard estimations for Blueys and Boomerang Beaches and associated uncertainty of the estimates.

The reasons for community concern regarding the erosion hazard assessment include the presence of boulder deposits located in the far corners of the beaches and the presence of bedrock (which is highly weathered in places) beneath the far corners of the beach (albeit at depths close to and below mean sea level; PWD, 1985). Some community members have suggested these two geological features provide evidence for bedrock being located beneath the backing dunes, such that some backshore areas would be protected from wave attack. Additionally, the beach erosion and recession hazard was estimated without proper consideration of the adjacent bedrock headlands. Rather, the hazard lines end in space towards the corners of both beaches, as opposed to being tied into the rocky headlands (see WorleyParsons, 2011). The incompleteness of these hazard lines inherently suggests there is some uncertainty surrounding the coastal geological system of Blueys and Boomerang Beaches.

In response to the above concerns, Great Lakes Council (Council) with the assistance of the NSW Office of Environment and Heritage (OEH) engaged BMT WBM to conduct a Ground Penetrating Radar (GPR) investigation at Blueys and Boomerang Beaches to investigate the physical (i.e. geological) nature of the beach and backshore environment. This study complements the Coastal Zone Management Study which BMT WBM is also currently undertaking for Council at the same location.

1.2 Study Aims

The aim of the present study is to conduct a GPR investigation to improve the knowledge of the coastal geological system at Blueys and Boomerang Beaches. The information gathered will be used to provide advice regarding the stability, or erodibility of the shoreline and adjacent backshore environment.

This study also aims to identify coastal sedimentary features of particular interest to the study in the GPR data, such as buried erosion escarpments which may provide some insight into the erosion history of the beaches.

1.3 Study Area

1.3.1 Regional Framework

Blueys and Boomerang Beaches are two small embayed beaches that are bounded by prominent rocky headlands of Charlotte Head to the north, Blueys Head to the south, and Boomerang Point which separates the two beach systems (Figure 1-1). The sandy shoreline of Blueys and Boomerang beaches are indented some 200-300 metres landward of the rocky headlands located along the study area coastline. Both beaches form moderately high energy coasts with an east-southeast aspect. The shorelines are sand dominated and backed by low incipient dunes, which are attached to the base of a steep and high barrier dune. Periodically exposed boulder beach deposits underlie the sandy shores in the far corners of both beaches.

Boomerang Beach is backed by a continuous barrier dune, which itself is backed by a transgressive dunefield comprising well stabilised dunes interspersed with a widespread deflation hollows (or ‘blowouts’) which are now well vegetated. Further westward, the transgressive dunefield leads into a low lying coastal plain that extends towards Elizabeth Beach. In contrast, Blueys Beach is backed by a barrier dune that is separated by a creek mouth further to the south. Behind much of the barrier, the land slopes towards a small natural drainage network in the south, before rising rapidly towards the steep bedrock hinterland.

1.3.2 Geological Framework

1.3.2.1 Bedrock

The bedrock geology of Blueys and Boomerang Beaches coastal region is comprised of Yagon Siltstone, a carboniferous-age sedimentary unit located within the Eastern Myall Block of the New England Fold Belt. The local geology is moderately deformed and metamorphosed, and has a dominant structure that trends broadly to the southeast (Roberts *et al*, 1991). This is evident in the coastal cliff outcrops adjacent Blueys and Boomerang Beaches, where the steeply inclined siltstone beds trend in the same direction. This geological structure has a significant role on the local coastal setting as indicated by the orientation of Blueys Head, Boomerang Point and Charlotte Head which all parallel the alignment of the underlying bedrock formations.

1.3.2.2 Coastal Sediments

A series of geological boreholes undertaken during the first coastal engineering investigation conducted at Blueys and Boomerang Beaches found a range of sediment types within the coastal zone (PWD, 1985). Key sediment types identified include:

- Clean sand;
- Silty sand, indurated in places;
- Clayey sand; and
- Stiff clay.

Title:

Blueys and Boomerang Beaches, Great Lakes Council Locality Map

Figure: 1-1

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Bedrock, weathered clayey-bedrock and ‘sandrock’ were also identified. Geological investigations undertaken as part of the PWD (1985) coastal engineering investigation identified the following key sediment units:

- Inner shelf sand – located well offshore of the beaches, below the -55 mAHD contour;
- Beach and nearshore sands – extending from the modern Holocene-age beach, seawards to a depth of around 55 m;
- Indurated sands – located beneath the barrier dune, and forming part of a relic, Pleistocene age coastal dune;
- Dune sands – no details provided, but possibly including the clean sands that cap the barrier dune; and
- Backbarrier sands – including all the clean (leached) sands located landwards of the barrier dune.

No interpretation was made of the clays located beneath the Blueys Beach barrier dune at and below sea level, but these may include relic Pleistocene-age lagoonal / estuarine sediments.

2 Brief Overview of Ground Penetrating Radar

Ground Penetrating Radar (GPR) is a non-invasive geophysical tool that collects high resolution images of shallow sub-surface conditions (typically depths of 5 -15 m, but varies considerably depending on the antenna used and the electromagnetic properties of the substrate). GPR methods are based on the transmission of high frequency electromagnetic (radar) waves into the ground, which become reflected off buried surfaces and objects and subsequently recorded by receiving antenna. GPR measurements can be used to identify both natural features (geological boundaries, sediment / soil layers, water table) and artificial materials (buried pipes, seawalls and other infrastructure). The following sections provide a brief overview of the GPR technique.

2.1 Data Collection and Display

GPR surveys are typically conducted along transect, or in a grid of transects where possible. Radar data is collected continuously along each survey line to produce a cross sectional profile of the subsurface reflection interfaces[1] (herein referred to as a radar profile). Along the transect, the GPR system transmits pulses of electro-magnetic energy into the ground from an antenna, which become reflected off buried interfaces back to the surface and received by an second adjacent antenna. This reflection information is recorded by the GPR system and displayed as a two-dimension reflection profile of the subsurface (i.e. the radar profile as shown on Figure 2-1). The returned radar data are displayed as a function of distance along the horizontal axis, and two-way travel time along the vertical axis.

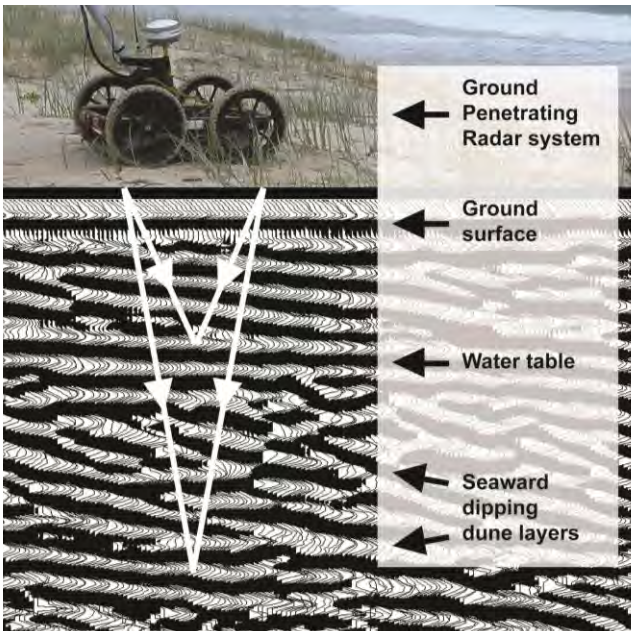

Figure 2-1 A 250 MHz Mala Unshielded Ground Penetrating Radar System with an Annotated Reflection Profile.

[1] Reflection interfaces occur due to changes in dielectric properties of the subsurface. This results from variations in the permittivity, conductivity and permeability of subsurface material (Jol, 2009). This generally arises in coastal environments at sedimentary bedding interfaces due to changes in sediment type and sorting. This also occur due to changes in subsurface saturation levels (i.e. at the water table), and may occur from changes in geological material.

The time taken for the transmitted radar pulse to reach an interface within the ground and become reflected back to the GPR system is relative to the subsurface wave propagation velocity, which is a function of the electrical and magnetic properties beneath the ground (Jol, 2009). In the case of coastal GPR investigations into unconsolidated sediments, the subsurface velocity is largely controlled by water content (Jol and Bristow, 2003). Depths of reflected surfaces and objects can therefore be estimated if the velocity structure of the radar profile is known, or can be approximated (Jol, 2009).

2.2 GPR systems

A range of antenna frequencies can be applied to GPR investigations to detect features at varying depths. However, for each antenna frequency there is an inherent trade-off between depth of penetration and resolution. Essentially, an increase in the antenna frequency results in an increase to the resolution of the survey data and a decrease to the effective depth of the survey. Thus lower frequency antennas are able to survey deeper subsurface features, whereas higher frequency antennas enable fine scale (near surface) features to be identified (Table 2-1).

Table 2-1 Theoretical Resolution of GPR at Blueys and Boomerang

Antenna Frequency (MHz)	Theoretical resolution in metres for a saturated sand (v = 0.06 m/ns[1])	Theoretical resolution in metres for a damp sand (v = 0.1 m/ns[1])
50	0.3	0.5
100	0.15	0.25
250	0.06	0.1

[1] Nano seconds

Antennas can also be configured to be ‘unshielded’ or ‘shielded’. Shielded antennas transmit a radar signal directly into the ground only, whereas unshielded antennas transmit radar energy in all directions including below and above ground surface. This can lead to unwanted signals being recorded from surface objects, such adjacent buildings and telegraph poles. For those reasons, shielded antennas are generally preferred in urban environments.

2.3 Data Processing and Interpretation

GPR data requires data processing to convert the raw radar data into meaningful geological information. At a minimum, data processing steps should include a series of signal filters, along with topographic correction (for profiles with varying topography) and display gains. Filters can be used to reduce ‘noise’ which is often present in raw datasets and accentuate the real subsurface geological signals. Topographic correction is used to correctly position each survey signal with respect to one another and to adjust for distortions within the radar profile. Display gains are applied to compensate for the inherent reduction in signal strength with depth, thus enhancing the deeper reflection that would otherwise be difficult to discern. Other processing steps include migration, which acts to correctly position distorted dipping and point reflections, and time-depth conversion to convert the vertical - two way time axis to depth, which can be applied with varying levels of accuracy. A single subsurface velocity can be applied to provide rough depth estimations, however a varying velocity profile (commonly including a two layer profile based on location of the water table) is often required to produce more accurate depth conversions.

2.4 Advantages and Limitations of GPR

The GPR technique works best in non-conductive media such as clean sand and is well suited to sandy coastal environments such as those considered by this study. GPR does not work well in conductive materials such as clays, or in saline ground conditions. In conductive conditions, the transmitted radar signal is rapidly absorbed by the subsurface media and little or no reflections are returned to the antenna. GPR is however capable of surveying subsurface conditions beneath a fresh water table. Considering this, coastal material below 0 mAHD can be successfully surveyed as the saltwater table wedges beneath the fresh water table away from the shoreline.

GPR is a very powerful geological tool when carefully applied to a suitable environment. In comparison to other geophysical techniques, GPR can rapidly survey subsurface conditions at a relatively high resolution and is a relatively cost effective technique. However, to maximise the likely success of an investigation, the GPR operator must have a good understanding of the GPR capabilities and limitations. The operator should also have some knowledge of the likely subsurface conditions of the target environment. Also, ground truthing the GPR data is often required to ensure the data interpretations are accurate.

3 Data Collection and Processing

3.1 Field Methods

3.1.1 Data Collection

A number of GPR surveys were conducted at Blueys and Boomerang Beaches over three consecutive days during July, 2013. The weather varied between showers and rain for the duration of the field survey program, and the ground conditions were generally wet.

A range of GPR antenna systems were applied in the field over a series of transects that cross cut the beach and backshore environments of both Blueys and Boomerang Beaches, which are discussed further below.

3.1.2 Equipment

A range of GPR systems were applied during the study, to capitalise on each of the radar system strengths (see Table 3-1) and to avoid any frequency-dependent interpretations.

The GPR surveys were conducted using a MALA X3M system with a 250 MHz and 100 MHz shielded antenna, and a MALA ProEx system with a 50 MHz unshielded rough terrain antenna. The 250 MHz antenna was configured with a MALA GPR Rough Terrain Cart, and the 100 and 50 MHz antennas were configured with a pull system which utilised an encoder wheel (100 MHz) and hip chain (50 MHz) to measure the survey distance. All measuring devices were calibrated in the field.

GPR transect paths and surface elevations were recorded using a Hemisphere S320 Real Time Kinematic (RTK) Global Positioning System (GPS). The roaming RTK GPS was mounted to each GPR system during their operation. The base RTK GPS was set up at Blueys Beach over the Newman Avenue (near Ampat Place) survey mark (SS78731) and at Boomerang Beach over the Boomerang Drive (near Angela Place) survey mark (SS78739).

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Table 3-1 Ground Penetrating Radar Antenna Systems Applied

Antenna Frequency and Type	Advantages	Disadvantages
250 MHz *(Shielded)*	**High vertical resolution** Very good a imaging detailed geological information (e.g. sedimentary bedding, small buried objects)	**Shallow depth of penetration** Data collected from the shallow subsurface only.
100 MHz *(Shielded)*	**Moderate vertical resolution** Very good at resolving primary geological boundaries, and subsurface features (e.g. sedimentary unit boundaries, some sedimentary bedding, water table)	**Moderate vertical resolution** Unable to resolve some of the finer subsurface features (primarily bedding), that can be imaged with the 250 MHz.

Antenna Frequency and Type	Advantages	Disadvantages
100 MHz *(Shielded)* *continued*	**Moderate depth of penetration** Capable of collecting near surface information from moderate depths at a reasonable resolution, allowing for reasonable interpretations to depths greater than the 250 MHz data.	**Data noisy in non-ideal environments** Data collected in semi-conductive substrates can be poor (e.g. some surfaced roads and clayey sands), with 'ringing' noise obscuring subsurface reflection data. **Physically large and wide antenna** Poor ground connection (coupling) over uneven surfaces, resulting in sub-optimal data collection results; and Unable to survey narrow pathways
50 MHz *(Unshielded - Rough Terrain Antenna)*	**Deep depth of penetration** Collects coarse scale information from depths notably deeper than the 100 MHz, however only prominent reflection surfaces are imaged (e.g. geological boundaries and primary sedimentary bedding). **Capable of surveying rough ground conditions** Capable of surveying through scrubby dune vegetation, over boulders and wooden beach access paths/steps.	**Unshielded antenna system** Radar pulses transmitted both below and above ground; reflections from surface features (e.g. telegraph poles, houses) often obscure subsurface features of interest. Also, susceptible to electromagnetic noise. **Low vertical resolution** Unable to resolve fine to medium scale subsurface features.

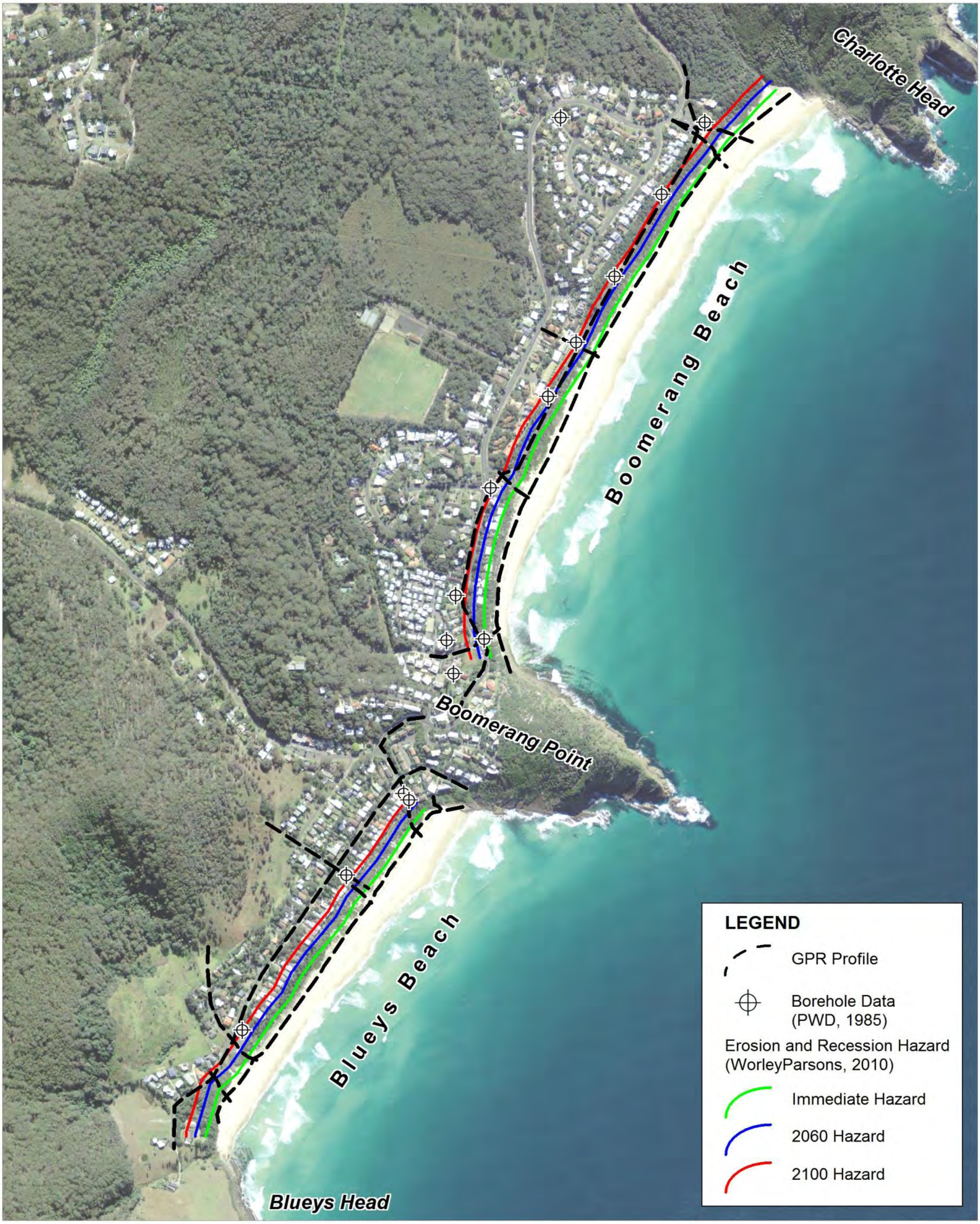
3.1.3 GPR Profiles - Survey Lines

A series of intersecting GPR profiles were surveyed across both Blueys and Boomerang Beaches, including both profiles orientated parallel with, and perpendicular to the shoreline. The survey plan (refer to Figure 3-1) was designed to investigate the three dimensional geometry of the subsurface sediment bodies and geological features.

Where practical, survey lines were designed to intersect with the existing geological boreholes and cross the boundaries of differing geological units expressed at the surface (i.e. the bedrock – sediment interface, such as where the sand dunes abut the rocky headland slopes). Both the borehole data and surface geological contacts provide a means of 'ground truthing' the reflection signals in the radar profile.

In summary, the key survey lines at both beaches included a:

- Shore parallel line along the foreshore, primarily the incipient dunes but also on the beach where required; and
- Shore parallel line along the backshore, including the barrier dune and headlands areas (on the north to south directed road and roadside reserves).



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Ground Penetrating Radar Survey Plan
Blueys and Boomerang Beaches, NSW

Figure: 3-1

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- Shore normal lines, cross cutting coastal barrier dune and foreshore profile (i.e. from the backshore to the foreshore), in the southern, central and northern reaches of each beach (using roads, road side reserves and beach access tracks).

A summary of each GPR profile is provided in Table 3-2 and Table 3-3. Detailed maps of GPR profiles presented in this study are presented with the interpreted GPR profiles in Appendix A.

Table 3-2 Boomerang Beach GPR Survey Summary

Radar Profile	Antennas Applied	Profile Location / Orientation	Surface Conditions	Data Presented?
GPR Boom 1	100, 50 MHz	Backshore – barrier dune profile / Shore parallel	Surfaced road, grassy road side reserve	Yes, in part (Figure A-2)
GPR Boom 2	250, 100, 50 MHz	Foreshore (incipient dune) profile / Shore parallel	Sand dunes and beach, incipient dune vegetation	Yes, in part (Figures A-3, A-4, A-6)
GPR Boom 3	250, 100 MHz	North backshore – foreshore profile / Shore normal	Surfaced road, grass/gravel, board and chain, sand	Yes (Figure A-5)
GPR Boom 4	250, 100 MHz	Central backshore – foreshore profile / Shore normal	Grass, concrete, surfaced road, wooden access path, sand	No (no new information)
GPR Boom 5	100 MHz	Central-south backshore – foreshore profile / Shore normal	Surfaced road, board and chain, sand	No (no new information)
GPR Boom 6	250, 100 MHz	South backshore – foreshore profile / Shore normal	Grassy road side reserve, surfaced road, gravel, board and chain, sand	Yes (Figure A-1)

Table 3-3 Blueys Beach GPR Survey Summary

Radar Profile	Antennas Applied	Profile Location / Orientation	Surface Conditions	Data Presented?
GPR Blue1	250, 100 MHz	Backshore – barrier dune profile / Shore parallel	Surfaced road, grassy road side reserve	Yes, in part (Figure B-2, B-5)
GPR Blue 2	250, 100, 50 MHz	Foreshore (incipient dune) profile / Shore parallel	Sand dunes and beach, incipient dune vegetation	Yes, in part (Figure B-3, B-6, B-7)
GPR Blue 3	250 MHz	Far north foreshore profile / Shore normal	Grassy slopes, rock rubble, sand	No (no new information)
GPR Blue 4	250, 100, 50 MHz	North backshore – foreshore profile / Shore normal	Surfaced road, grassy road side reserve, sand	Yes (Figure B-4)

Radar Profile	Antennas Applied	Profile Location / Orientation	Surface Conditions	Data Presented?
GPR Blue 5	250, 100 MHz	Central backshore – foreshore profile / Shore normal	Grassy/swampy slopes, roadside reserve, surfaced road, wooden access path, incipient dune vegetation, sand	No (no new information)
GPR Blue 6	250, 100 MHz	South backshore – foreshore profile / Shore normal	Grassy/swampy slopes, roadside reserve, surfaced road, sand	No (no new information)
GPR Blue 7	250, 100 MHz	Far south backshore – foreshore profile / Shore normal	Surfaced road, roadside reserve, sand	Yes (Figure B-1)

3.2 Data Processing and Interpretation

3.2.1 Data Processing

A series of processing steps were applied to convert the raw Mala GPR data into meaningful and interpretable geological information. The sequence of processing steps applied to this study are summarised in Figure 3-2 and important notes regarding the key data input and data processing steps are detailed below. All data processing was conducted with ReflexW.

3.2.1.1 Elevation Data

The RTK GPS returned accurate horizontal - location (i.e. coordinate) data, but poor quality vertical - elevation data. The GPS coordinate tracks for each transect was used to extract the elevation information from the existing high resolution, LiDAR derived Digital Elevation Model (DEM). These elevation data are considered to be accurate, considering the GPR surveys were primarily conducted on stable landforms including vegetated dunes and urbanised backshore areas (as opposed to the active beach face, for example, where the surface topography changes over time).

3.2.1.2 Filters

A common sequence of filters was applied to all the GPR data. The parameters of each filter were specifically tailored to the 250 MHz, 100 MHz and 50 MHz datasets. The filters applied include an initial filter to remove the signal saturation ('dewow'), followed by temporal ('band pass') then spatial filters (variable, depending on individual profile) to reduce the noise within the dataset.

3.2.1.3 Migration

Migration was tested on all GPR radar profiles using a single velocity model of 0.10 m/ns. This step was however omitted from the final processing sequence in a number of cases where it did not improve the output.

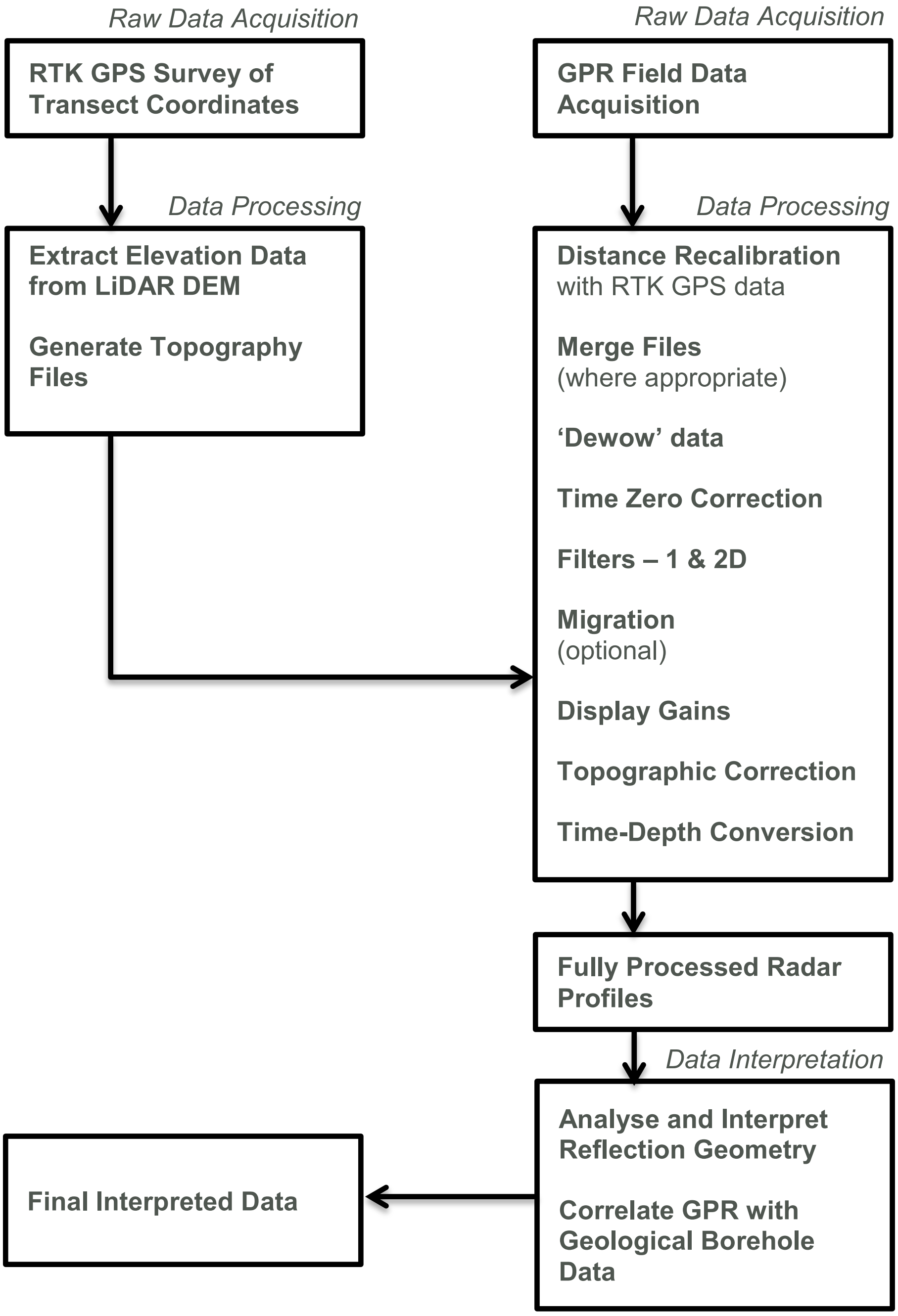


Figure 3-2 Blueys and Boomerang GPR Processing Flowchart

3.2.1.4 Display Gain

Two separate gain functions were applied to the processed data, including an Automatic Gain Control (AGC) function and a user defined function. The AGC gain equally enhances all reflection signals (including real information and noise). The user defined function retains the relative amplitude information, allowing important reflection information (i.e. the relative amplitude of the reflection) to be retained. Both versions of the processed radar profiles were used for the interpretation, however profiles presented in this report correspond to the outputs processed with the AGC function.

3.2.1.5 Topographic Correction

GPR topography files were generated using the elevation data extracted from the LiDAR digital terrain model. A velocity of 0.1m/ns was applied to convert the topography information into two-way-time (which is the required format).

3.2.1.6 Velocity Estimation and Time-Depth Conversion

Time-depth conversions were made assuming the radar profiles comprised a two layered velocity structure that varied about the water table. A velocity of 0.10 m/s was used for the upper layer (i.e. above the water table) and a velocity 0.06 m/s for the lower layer which are based on the theoretical velocities for damp sand and saturated sands respectively (Bristow and Jol, 2003). The damp sand velocity was applied to the upper layer due to the wet weather conditions that prevailed throughout the field program. Comparison of borehole data indicated that the velocity estimation of 0.10 m/ns was appropriate for the upper layer.

3.2.2 Radar Profile Interpretation

GPR data were interpreted using the principles of radar stratigraphy (as per Neal, 2004), to identify various sedimentary units and define a relative timeline of coastal depositional history. Available geological borehole data and surface geological relationships were used to ground truth the GPR interrelations.

The processed GPR data was interpreted with line drawings to simplify the reflection structures and highlight important features and sedimentary relationships. The two key geological features targeted by this investigation included:

- bedrock beneath coastal sediments; and
- erosion escarpments within the barrier dune

An additional geological feature of interest was the boulder beach deposits which were well exposed at the south end of Boomerang Beach during the survey.

A summary of terminology used to describe reflection geometry to assist with the profile interpretation is shown in Figure 3-3.

3.2.2.1 Expert geomorphic interpretation

Geomorphic interpretation of the coastal sediment and bedrock landforms at Blueys and Boomerang Beach was also conducted. Well established principles of coastal evolution were drawn upon where appropriate (e.g. wave-dominated coastal sedimentary models in Roy *et al.,* 1994).

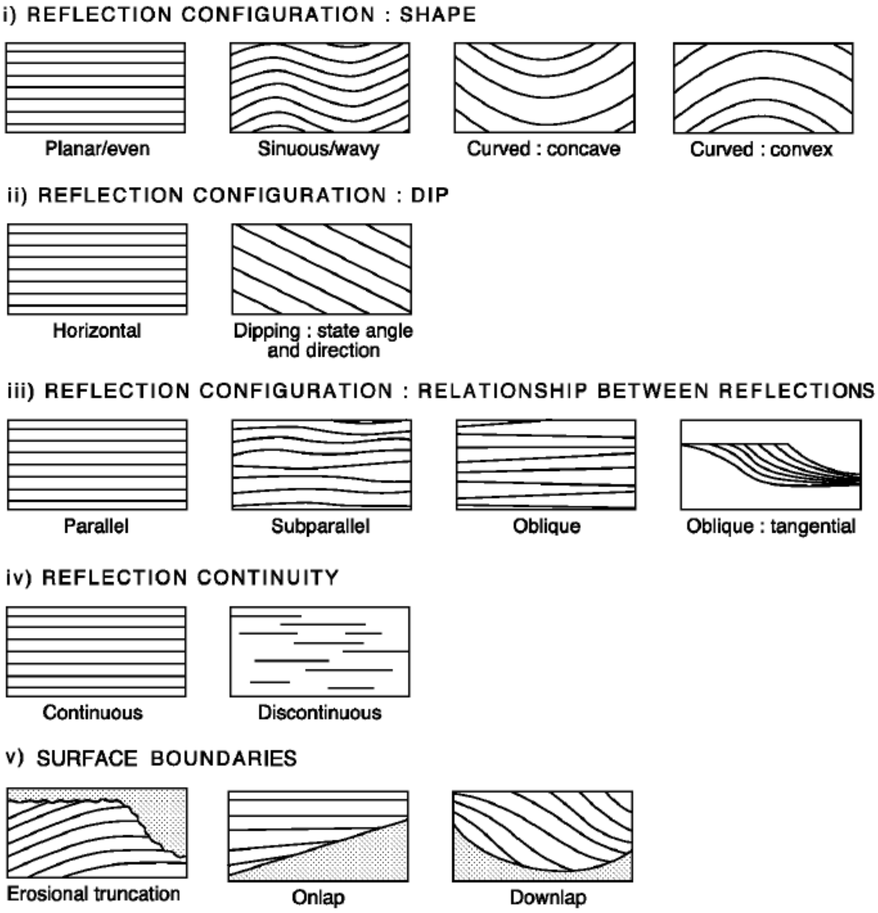


Figure 3-3 Descriptive GPR Terminology for Sedimentary Reflection Patterns (modified from Neal, 2004).

4 GPR Survey Results

4.1 Boomerang Beach

The GPR profiles from Boomerang Beach identify a number of key coastal geological units and relationships, as shown in Figures A-1 to A-6 of Appendix A and described below. Refer to Figure 4-2 for location details regarding radar profiles and geological boreholes.

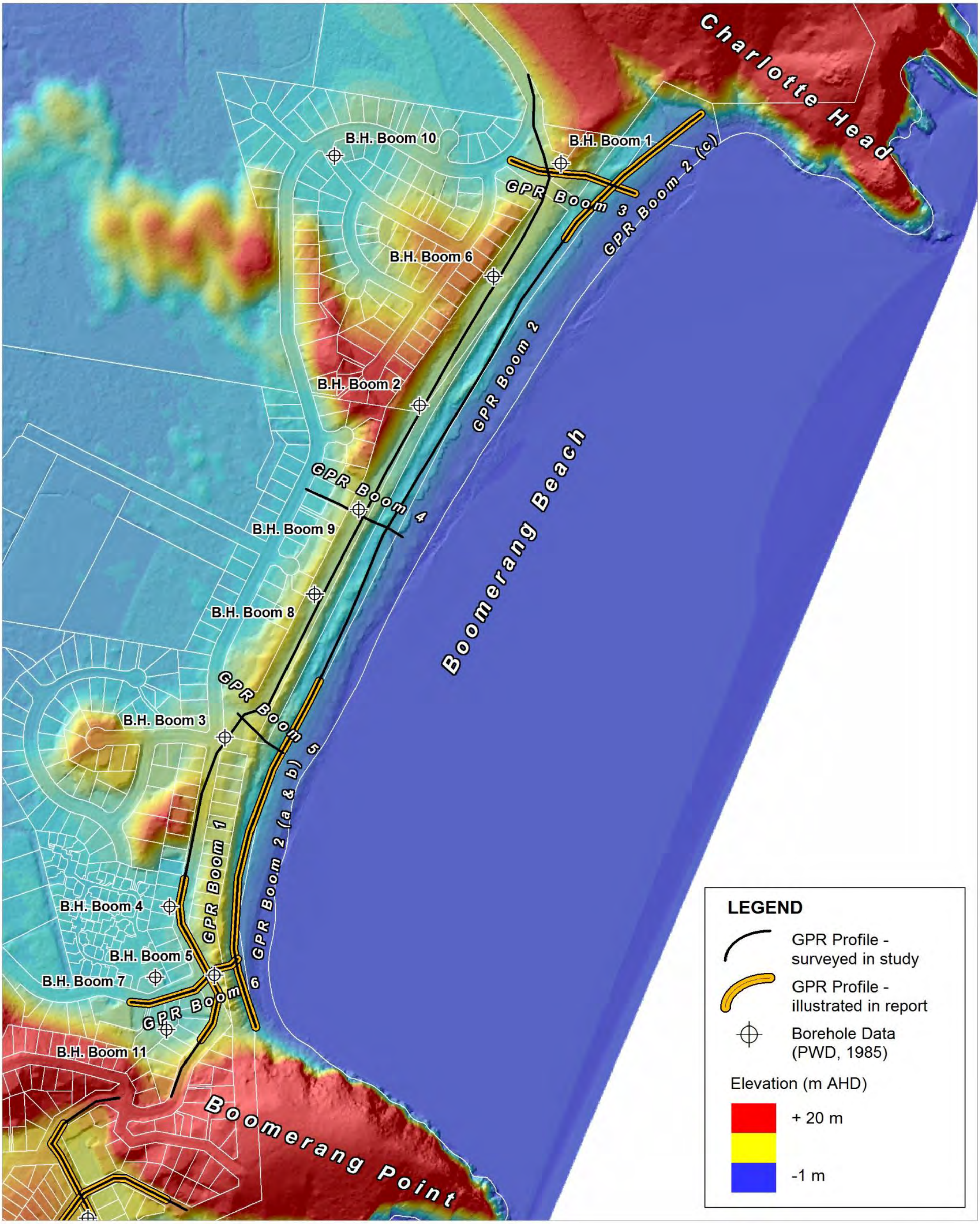
4.1.1 Beach

4.1.1.1 Landform Description

Boomerang Beach is an embayed beach approximately 1400 metres in length. The beach is laterally bounded by the rocky Boomerang Point to the south and Charlotte Head to the north. Backing the beach is a near continuous incipient dune, which itself is backed by large barrier dune.

Boomerang Beach is a modern (Holocene-age) landform composed primarily of sands for much of its length. A significant boulder beach deposit underlies the southern end of the sandy beach and incipient dunes. The boulders become exposed under eroded conditions, such as those occurring at the time of the field investigation (Figure 4-1).

Figure 4-1 Exposed Boulder Beach Deposits at Southern Boomerang Beach, July 2013.



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GPR Survey Plan and Borehole Locations
Boomerang Beach, NSW

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4.1.1.2 Radar Results

Beach deposits surveyed at Boomerang Beach are shown in Figures A-1 and A-3 to A-6 (Appendix A).

4.1.1.3 Radar interpretation

Reflections from the beach deposits at Boomerang Beach are somewhat variable, depending on the orientation of the survey and the sediment type. The beach sediments were typically imaged from below 0 to 3 m AHD from the active beach and beneath the incipient dunes. The sandy beach reflections from the shore normal profiles (GPR Boom 2) mostly comprise gently seaward dipping planar to concave up reflections (Figure A-1 and A-5), whereas the shore parallel profiles show the beach beds as near continuous sub-horizontal reflections (Figure A-3, A-4 and A-6).

The boulder beach deposits at Boomerang Beach are differentiated from the sandy beach by the presence of convex up (i.e. hyperbolic) reflections. The southern boulder deposit appears extend for some 300 to 400 metres along the beach (see Figure A-3 and Figure A-4). A shallow northerly dipping reflection interpreted as the top of the boulders shows the boulders beach to wedge out in thickness some 250 metres north of Boomerang Point (Figure 4-3). Hyperbolic reflections in the far northern corner of the beach also indicate that boulders underlay the sandy beach in the location, which appears to be a more localised deposit, based on the relatively limited extent of the hyperbolic reflections in this area (Figure A-6).

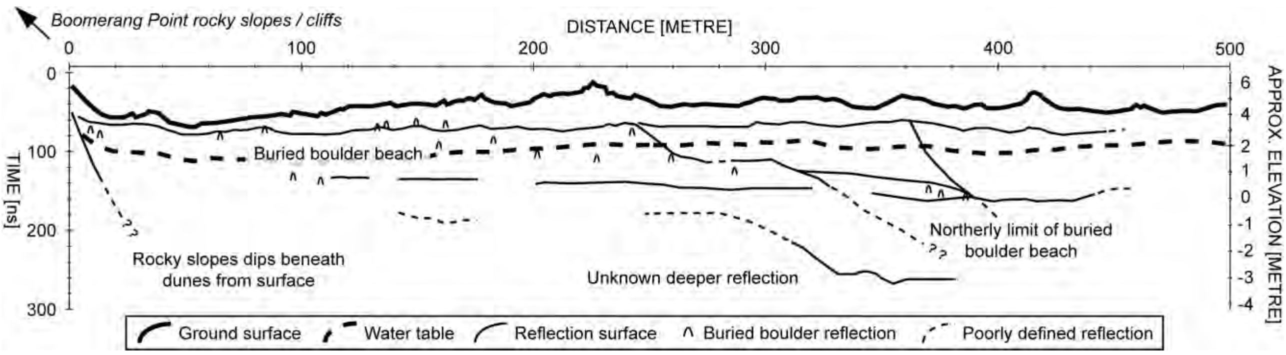


Figure 4-3 Southern Boomerang Beach Incipient Dune GPR Interpretation, showing the Buried Boulder Beach Deposit and Steeply Sloping Bedrock Surface
(Refer Figure A-3 and A-4 for details)

4.1.2 Coastal Dune System

4.1.2.1 Landform Description

A well-established and continuous barrier dune ranging in height from 10 to 14 metres backs the length of Boomerang Beach. The barrier dune is immediate fronted by a 3 – 7 metre high incipient dune that is variable in width and occasionally separated from the barrier dune by a shallow swale.

Landward of the barrier dune is a transgressive dunefield which includes an extensive deflation hollow (backbarrier swamp) in the south and a variably high, well established dune field in the north. The northern transgressive dunes commonly reach elevations 20 m AHD and more. The barrier dune has a notably steep profile on its seaward side.

Geological borehole data shows that the barrier dune to be comprised of a clean sandy surface deposit mostly underlain by silty sands which are indurated in places (PWD, 1985). This sediment profile is interpreted by PWD (1985) as relic (Pleistocene-age) dune sediments that have undergone strong podsolization. This may be an over simplification of the barrier dune sediment profile as indicated by the presence of a buried modern (Holocene-age) soil horizon at southern Boomerang Beach (PWD, 1985) which shows that recent aeolian dune sands cap the relic barrier dune at least in part. Geological borehole data also show the barrier dunes to be underlain by bedrock in the far corners of the beaches (see Section 4.1.3).

4.1.2.2 Radar Results

The coastal dune system at Boomerang Beach was surveyed by GPR profiles shown in Figures A-1 to A-6 (Appendix A).

4.1.2.3 Radar Interpretation

A range of dune types were surveyed at Boomerang Beach, including incipient dunes, the barrier dune and fringes of the transgressive dune field. The shore parallel surveys from the incipient dune show a near continuous and mostly horizontal reflection at around 3 - 4 mAHD (Figure A-3, A-4, and A-6). This reflection is interpreted as the boundary between the beach sediments and overlying and incipient dune sands.

The dune types described above were surveyed in part by the shore normal profiles (Figure A-2 and A-5). Seaward dipping reflections are common from within the foreshore side of the barrier dune and within the incipient dunes (Figure A-1 and A-5). These are interpreted as aeolian accretion bed forms that were deposited from sand being blown off the beaches and onto the dune face. Discontinuous barrier dune and incipient dune reflections that are truncated by steeper reflections were imaged and are interpreted as buried erosion escarpments (see Section 4.1.4).

A confused wavy reflection signature located behind the barrier dune crest in the northern Boomerang Beach (GPR Boom 3; Figure A-5) correlates with the relic (Pleistocene-age) silty sands deposits intercepted within Borehole B.H. Boom 1. No such reflections were identified at southern Boomerang Beach (GPR Boom 6; Figure A-1). This may indicate the far southern barrier dune comprises modern (Holocene-age) sediments only.

Landwards dipping reflections were located on the landwards side of the barrier dune. These are interpreted as dune sands that have been blown over the barrier dune crest and deposited on the leeward slope. This process has led to the development of the large transgressive dunes that occur within the northern backshore environment of Boomerang Beach.

4.1.3 Bedrock – Sediment Interface

4.1.3.1 Observed Geological Contacts

The Boomerang Beach coastal sedimentary system is bounded by the rocky Boomerang Point in the south and Charlotte Head in the north (Figure 4-2). The nature of the geological contact between the coastal sediments and adjacent rocky headlands is largely unknown within the

Boomerang Beach coastal zone, particularly within the subsurface. Some information does however exist towards the ends of the beach, including:

- Borehole B.H. Boom 5 from the barrier dune in the far south, which shows weathered bedrock at 0 mAHD; and
- Borehole B.H. Boom 1 from barrier dune in the far north shows bedrock at -1.1 mAHD.

Geomorphic interpretation of the landscape can also provide some insight into the likely location of bedrock in the near subsurface at Boomerang Beach, as follows:

- Submerged rocky shore platforms are located in the far corners of the beach and most notably in the south. These were observed in the field and identified in the 2010 aerial photography. The presence of near shore rock reef indicates that bedrock in the form of a buried rock platform also underlies the beach immediately inland of the rocky exposures at an elevation around mean sea level to mean low water; and
- Where coastal beach and dune sediments can be confidently interpreted to onlap (i.e. abut onto or overlap) adjacent rocky headlands, the bedrock - sediment boundary can be estimated at the surface. In such scenarios, the bedrock - sediment interface typically occurs at the topographic break in slope. This is the case at southern Boomerang Beach, where the LiDAR DEM clearly shows the barrier dune to abut the headlands slopes along an east to west line that projects inland of the adjacent coastal cliffs.

Despite the known and interpreted spot locations of the bedrock as described above, the three dimensional geometry of the coastal sediment – bedrock contact cannot be entirely discerned from this information.

4.1.3.2 Radar Results

The GPR surveys investigating the presence of bedrock at Boomerang Beach are shown in Figures A-1 to A-3 (southern Boomerang Beach) and A-5 to A-6 (northern Boomerang Beach) in Appendix A.

4.1.3.3 Radar Interpretation – South Boomerang Beach

A moderate to steeply northward dipping reflection imaged at shallow depths in the far southern end of Boomerang Beach is interpreted as a bedrock reflection. This is observed at 30 - 40 metres chainage in GPR Boom 1 and 0 – 10 m chainage GPR Boom 2a (Figure 4-3, Figures A-2 and A-3), and forms the bedrock – sediment interface between the Boomerang Beach coastal sediments and the bedrock substrate of Boomerang Point. The location of this reflection also correlates well with the landscape interpretation described previously, as the bedrock reflection from these two surveys are located at the break in slope near the base of Boomerang Point, and resolved to depths of 2 - 3 m below the surface.

The imaged bedrock surfaces are interpreted to form a coastal slope which has been buried by the formation of the barrier dune. It is therefore considered that the buried bedrock surface has a similar profile to the modern rocky coast of Booomerang Point comprising steep to cliffed rocky slopes that adjoin a wide sub-horizontal platform at around sea level. As such, the buried rocky surface is interpreted to dip moderately northwards to around 0 m AHD where it flattens out for some distance northward (possibly 70 – 100 metres, as per the submerged rock reef exposed adjacent to the beach).

This interpretation agrees with the geological borehole data (B.H Boom 5; PWD, 1985), which shows weathered bedrock located beneath the barrier dune at around 0 m AHD some 70 metres north of Boomerang Point. Other borehole data show that the no rocky substrate underlies the southern beach distances greater than approximately 150 metres north of Boomerang Point.

With regards to the stability of the coastal system at southern Boomerang Beach, the presence of beach and dune reflection to depths of 2 m AHD shows that the shoreline is susceptible to erosion and recession. That is, the presence of sedimentary reflection depths near sea level (i.e. north of the imaged Boomerang Point rocky slope: N 6,421,070 m GDA94) indicate that bedrock is not present in any protective capacity.

4.1.3.4 Radar Interpretation – North Boomerang Beach

Clear sedimentary reflection to depths of 1 m AHD along the northern foreshore (GPR Boom 2c) and 3 mAHD beneath the northern barrier dune (GPR Boom 3) indicate that bedrock is absent above these heights (Figures A-5 and A-6).

Borehole B.H Boom 1 shows that bedrock is located at a depth of -1.4 m AHD beneath the barrier dune in the north (PWD, 1985); however no bedrock rocky interfaces were imaged in the GPR profiles from this region (Figures A-5 and A-6). As such, the geometry of the bedrock surface between northern borehole (B.H. Boom 1) and the far northern rocky shores of Charlotte Head is unknown. Well vegetated and elevated slopes rise to above 20 metres behind the shoreline in this area.

With regards to the underlying bedrock morphology in this local area (i.e. north of the northern car park at Boomerang Beach), there are two likely scenarios:

- The elevated backshore terrain is comprised of bedrock slopes which are resistant to erosion; or;
- The elevated backshore slopes are comprised of high transgressive dunes that are underlain by a buried rocky shore platform that adjoins Charlotte Head, north of the unnamed creek line.

Considering the coastal rocky slopes of this region are strongly controlled by the underlying structure of the bedrock geology (which has a northwest strike at northern Boomerang Beach), the later scenario is considered most likely. This scenario would see the buried bedrock slopes of Charlotte Head extend landwards of the beach and beneath the vegetated slopes, in line with the modern rocky cliff line (i.e. in a north-westerly direction). Immediately south of this interpreted bedrock surface, the beach is assumed to be backed by high vegetated sand dunes that overly a buried rocky shore platform (just below mean sea level), similar to that previously described for southern Boomerang Beach.

As such, for the purpose of this study the shoreline between Boomerang Beach's northern car park and Charlotte Head is considered to be vulnerable to wave erosion and shoreline recession.

Additional borehole drilling or alternate geophysical techniques suited for use in thickly vegetated terrain could be employed to further investigate the presence of bedrock in this area if necessary.

4.1.4 Buried Erosion Escarpments

4.1.4.1 Landform Description

Steep erosion escarpments are formed when the beach and dunes become eroded after a large storm event. Depending on the severity of the storm and the preceding beach state (i.e. eroded or accreted condition), the storm bite may erode into the incipient dunes only, or else continue landwards into the barrier dune. Following this, the steep erosion escarpment can become progressively buried by beach and dune sediments when the shoreline subsequently becomes accreted and the dune system begins to recover.

Old erosion escarpments can remain in the landscape when they become only partially buried by subsequent dune accretion. This is usually expressed within the coastal dune profile as a steep seaward dipping slope that parallels the shoreline and is located landwards of the modern incipient dune front. Where an old erosion escarpment becomes entirely buried by dune accretion, the steep scarped profile remains as a subsurface sedimentary feature only.

The moderately steep dipping seaward slope of the Boomerang Beach barrier dune system has a profile indicative of an old erosion escarpment for most of its length. This steep face may have formed during a large storm event (mid-1970's?) where wave erosion progressed into the barrier dune. The old escarpment face has since undergone some accretion and become well vegetated. A less conspicuous and discontinuous ridge line within the centre region of Boomerang Beach incipient dunes is also interpreted as a younger (post mid-1970's) erosion escarpment.

4.1.4.2 Radar Results

The GPR surveys which investigated the presence of buried erosion escarpments at Boomerang Beach are shown in Figures A-1 and A-5 (Appendix A).

4.1.4.3 Radar Interpretation

Buried erosion escarpments can be identified in a radar reflection profiles, based on the geometric relationships of the reflection signals. Typically, erosion escarpments are expressed as steep seaward dipping reflections that truncate one or more dune reflections on its landwards side. That is, dune reflections typically terminate abruptly against the steep erosion reflection. Reflections from beach and dune sands deposited after the erosion event are also found to onlap the seaward side of the buried escarpment reflection (Figure 4-4).

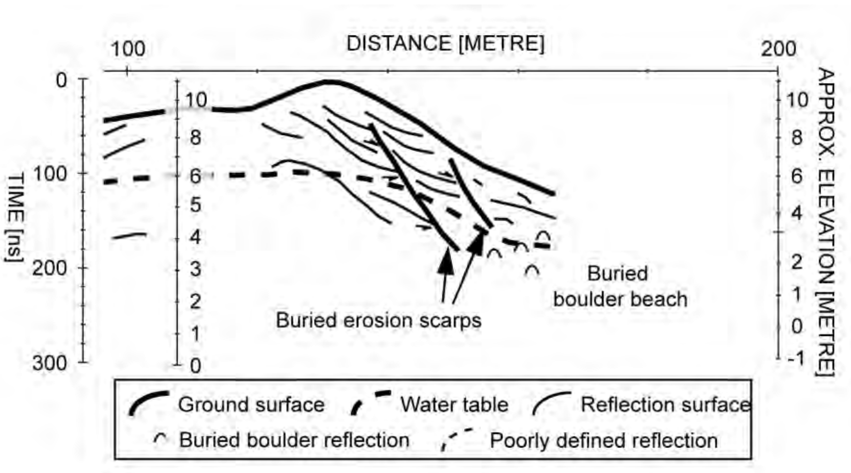


Figure 4-4 Southern Boomerang Beach Barrier Dune GPR Interpretation, showing the Buried Erosion Escarpment Locations.
(Refer Figure A-1 for details)

Two buried erosion escarpments were identified within the shore normal profiles at southern Boomerang Beach (GPR Boom 6; Figure A-1). The most prominent scarp is located just landwards of the barrier dune crest, and the other at the seaward edge of the barrier dune. The seaward most (and hence younger) scarp correlates well with the 1975 photogrammetric profile for this location, as shown in WorleyParsons (2011; Figure B.3a, Block A502, Profile 2). The more landwards scarp located beneath the barrier dune crest does not agree with any photogrammetric profiles and is located further onshore than all of the shoreline position identified with the photogrammetric profiles. The buried scarp therefore represents an erosion profile that pre dates the near 60 year old photogrammetric record.

A well-defined reflection interpreted as a buried escarpment was also identified beneath the barrier dune crest from northern Boomerang Beach (GPR Boom 3; Figure A-5). Interestingly, the reflection signatures either side of this scarp are quite varied. On the seaward side, the reflections are well defined and clearly represent accretion of modern beach and dune sediments; however on the landwards side the reflections are confused. The reflection signals here correlate well with the silty sands identified in borehole B.H. Boom 1 which are Pleistocene in age (PWD, 1985). As such, this scarp likely forms the erosion boundary between the relic barrier dune and the modern coastal system.

4.2 Bluey Beach

The GPR profiles at Boomerang Beaches identify a number of key coastal geological units and relationships, as shown in Figures B-1 to B-7 (Appendix B) and described below. Refer to Figure 4-6 for location details regarding Blueys Beach radar profiles and geological borehole.

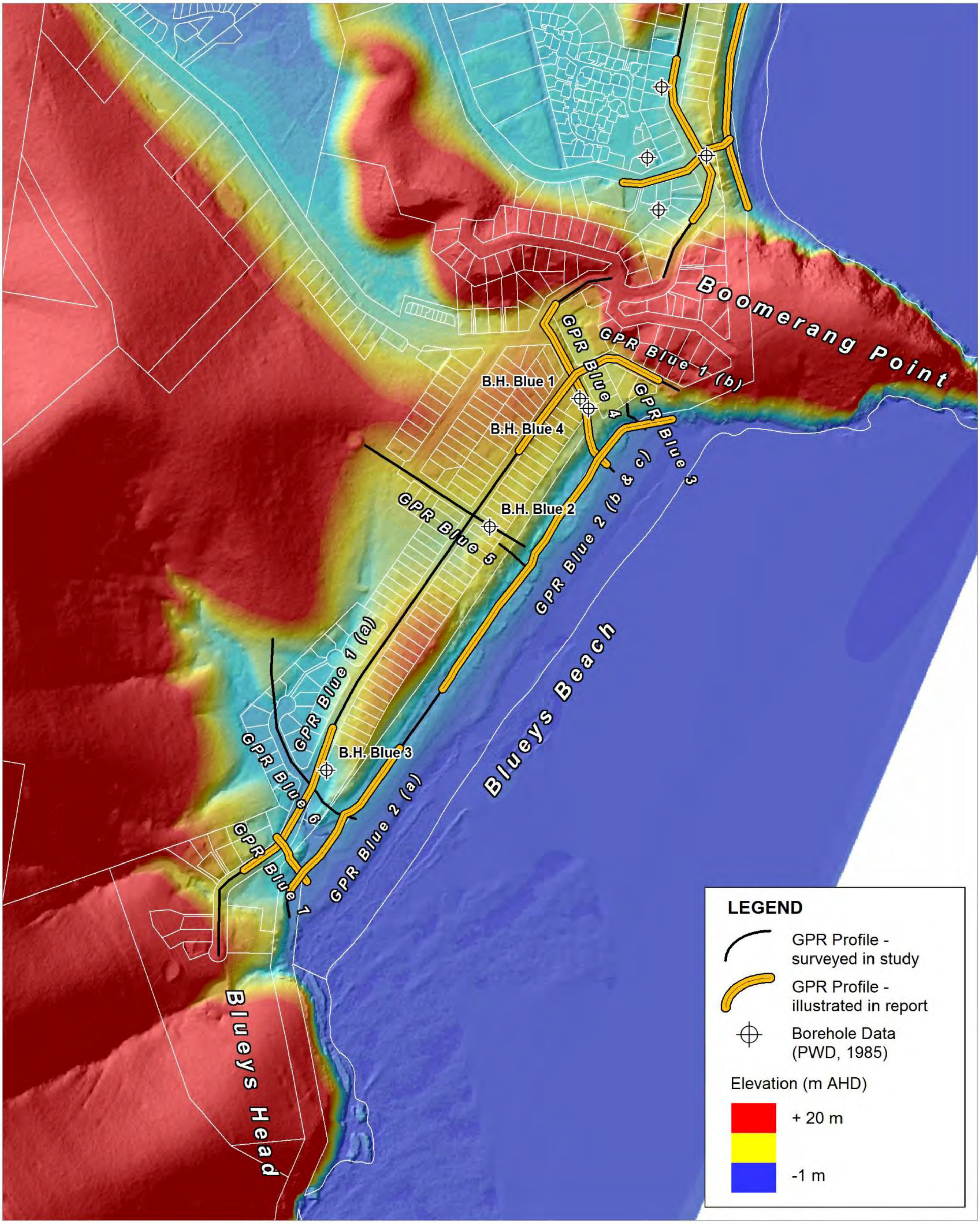
4.2.1 Beach

4.2.1.1 Landform Description

Blueys Beach is an 850 metre long embayed beach bounded by the Blueys Head to the south and Boomerang Point to the north. The beach is immediately backed by a near continuous incipient dune, which itself is backed by large barrier dune. The barrier dune reduces in height southwards, towards a small unnamed creek that intermittently flows through the southern end of the beach.

The beach is a modern (Holocene-age) landform and primarily composed of sand, with some boulders present at the far ends of the beach. Historical photographs of Blueys Beach following the May 1974 storm event (Figure 4-5) show that a boulder deposits underlies the sand at the northern end of the beach. Some boulders and gravel were also observed in the far southern corner.

Figure 4-5 Exposed Boulder Beach at Northern Blueys Beach, Following a Severe Storm in May 1974 (Source: WorleyParsons, 2011)



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Blueys Beach, NSW

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4.2.1.2 Radar Results

Beach deposits surveyed at Blueys Beach are shown in Figures B-1, B-3, B-4, B-6 and B-7 (Appendix B).

4.2.1.3 Radar Interpretation

Beach reflections were returned between approximately 0 – 3 mAHD from Bluey Beach in the form of sub horizontal reflections from the incipient dune - shore parallel profile (GPR Blue 2; Figure B-3, B-6 and B-7) and planar to slightly concave up shaped reflections from the shore normal profiles (GPR Blue 4 and 7; Figure B-1 and B-4). Occasionally deeper reflections were also returned from depths between 0 to -2 m AHD.

Hyperbolic (convex up) reflections from buried boulders were also recorded from the far corners of the Blueys Beach, particularly in the north. Here a southerly dipping reflection between approximately 760 – 890 metres in GPR Blue 2c is interpreted as a sedimentary layer within the buried boulder deposit (Figure B-7). A second southerly dipping reflection was recorded between that previously described and the headland (chainage 860 - 930 metres). This feature was imaged in the 50 MHz profile as low amplitude reflection and is interpreted as a buried rocky shore platform. Thus the buried rocky platform also forms the base of the boulder deposit in that area (see Section 4.2.3). Unlike at southern Boomerang Beach, the alongshore extent of Blueys Beach boulder deposits was not clearly defined. However the absence of hyperbolic reflections across much of the middle beach indicates the boulders are restricted to the far corners.

A horizontal reflection from -2 m AHD was recorded in the 50 MHz shore parallel profile (GPR Blue 2, 210 to 310 m chainage; Figure B-3). Given that the boreholes B.H. Blue 2 and 3 show that no rocky substrate is located beneath the barrier dunes central region (PWD, 1985), the -2 m AHD reflection was likely sourced from an upper shoreface sedimentary layer, as opposed to a bedrock surface.

The unshielded 50 MHz incipient dune - shore parallel profile (GPR Blue 2) contains a number of reflections returned from objects above the ground surface (Figure B-3, B-6 and B-7). Above ground radar reflections are known as “air-reflections”, which can occur from unshielded antennas only (note the 100 and 250 MHz antennas were shielded, and thus contain reflections from surface objects only). Air reflections can be identified from true geological reflections, as they typically take the form of broad hyperbolic reflections and/or reflections that cross cut other signals in the profile identified as true subsurface features. Prominent air-reflections from the foreshore houses have been recorded throughout the incipient dune – shore parallel profile, notably occurring at two-way times of 400 ns across the middle beach areas. These do not represent a deep geological surface and thus have not been added to the line interpretations (Figure B-3, B-6 and B-7).

4.2.2 Coastal Dune System

4.2.2.1 Landform Description

A well-established barrier dune ranging in height from 12 to 20 m backs Blueys Beach, from Boomerang Point in the north to an unnamed creek mouth near Ampat Place towards the south. South of this creek, a small foredune is located behind the beach. The seaward edge of the barrier dune is notably steep, which is immediately fronted by a mostly continuous incipient dune reaching heights of 4 – 7 mAHD. Backing the barrier dune is varying topography that ultimately adjoins bedrock terrain located some 200 metres inland of the barrier crest. A small drainage depression separates the bedrock hinterland from the central to southern section of Blueys Beach barrier dune. The base of this local drainage depression is low (4 to 5 m AHD) and becomes periodically flooded from coastal inundation during large storm events.

Geological borehole data from the middle to northern sections of Blueys Beach shows the barrier dune to have a similar composition to that at Boomerang Beach, including a clean surface sand layer underlain by silty sands at depth (B.H. Blue 1, 2 and 4; PWD, 1985). Where the barrier dune reduces in height and width towards the creek, borehole data shows the dune to comprise clean sands underlain by clayey sands (B.H. Blue 3; PWD, 1985). The clayey nature of the lower sediments indicates a possible alluvial or lagoonal origin.

All four of the PWD (1985) boreholes from Bluey Beach intercept a stiff clay unit at around 0 mAHD (+/- 2 m). This unit is interpreted here as a relic (Pleistocene-age) estuarine/lagoonal sediments. The clay layer overlies bedrock at or below mean sea level in the northern most boreholes and extends below -3 m AHD elsewhere (PWD, 1985).

4.2.2.2 Radar Results

GPR profiles of Blueys Beach coastal dune system are shown in Figures B-1 to B-7 (Appendix B).

4.2.2.3 Radar Interpretation –south Blueys Beach

The shore normal radar profile GPR Blue 7 surveyed the small foredune south of the unnamed creek at Blueys Beach (Figure B-1). This profile shows concave up reflections dipping both landwards and seaward of the dune crest, which are interpreted as dune layers. An inclined reflection extends beneath the foredune beginning from near the surface on the dunes landward side. This is interpreted to be the relic land surface which the foredune subsequently developed on. The geological composition of this buried land surface is unknown, but possible indurated sands as observed outcropping on the at the back of the beach adjacent to GPR Blue 7 (Figure 4-7).

Figure 4-7 Indurated Silty Sands with Gravels Exposed at the Base of Southern Blueys Beach.

4.2.2.4 Radar Interpretation – Mid to North Blueys Beach

Reflections from the shore parallel – incipient dune surveys (GPR 2; Figure B-3, B-6 and B-7) show a near continuous and level reflection at about 3 m AHD. This is interpreted as the boundary between the incipient dunes and the underlying beach sediments. Above this, the incipient dune layers were found to be both horizontal and dipping, and occasionally wavy in form.

Shore normal profiles from the northern (GPR Blue 4, Figure B-4) and middle (GPR Blue 5, not shown) sections of Blueys Beach surveyed the incipient dunes, barrier dune and backshore slopes. Seaward dipping reflections returned from beneath the incipient dunes were found to abut onto a steeper seaward dipping reflection located at the seaward edge of the barrier dune. This reflection geometry is indicative of a buried erosion escarpment and is interpreted as an erosion scarp from the stormy 1970's period (e.g. scarp shown in Figure 4-5).

Another moderately inclined seaward dipping reflection is also present beneath the barrier dune in both GPR Blue 4 and 5, approximately 20 – 30 metres landwards of the steep barrier dune face. The reflection surface here may represent an older erosion escarpment and/or the landwards boundary between the modern (Holocene) and relic (Pleistocene) barrier dune deposits.

Ground survey conditions from the northern Blueys Beach barrier dune were not great and the data quality from those areas is moderate to poor. However, faint westerly dipping reflections have been recorded from 100 MHz data in backshore areas (Figure B-4), which suggests that the high ground backing the barrier dune crest also comprises transgressive dune sediments.. This is not surprising given the widespread (relic) landward migrating dune field present at Boomerang Beach.

4.2.3 Bedrock – Sediment Interface

4.2.3.1 Observed Geological Contacts

Blueys Beach is a bedrock bound beach and dune system. The nature of the bedrock contact between the Blueys Beach coastal sediments and the Blueys Head to the south, Boomerang Point to the north and the backing rocky hinterland slopes is mostly unknown. Some information regarding this geological contact exists for the northern end of the beach, including:

- Borehole B.H. Blue 1 from the barrier dune in the far north, which shows bedrock at 0.4 mAHD; and
- Borehole B.H. Blue 4 also located on the barrier dune crest (some 20 m seaward of B.H. Blue 1), which shows bedrock at -2.2 mAHD (PWD, 1985).

This borehole information indicates that the buried bedrock surface beneath the far northern barrier dune slopes seawards in an apparent south-easterly direction.

The presence of submerged rocky shore platforms located immediately offshore of the beach ends also indicates that the adjacent sandy shoreline is underlain by rock. The buried rocky platform potentially extends inland beneath the backing barrier dune to adjoin the bedrock surfaces identified in B.H. Blue 1 and 4 (PWD, 1985).

Geomorphic interpretation of the landscape indicates that some areas with moderate to steeply inclined slopes (e.g. Blueys Head and Boomerang Point) are formed of bedrock and thus not susceptible to wave erosion.

4.2.3.2 Radar Results

The GPR surveys investigating the presence of bedrock at Blueys Beach are shown in Figures B-1 to B-3 from southern Blueys Beach and Figures B-4, B-5 and B-7 from northern Blueys Beach, in Appendix B.

4.2.3.3 Radar Interpretation – South Blueys Beach

Radar profiles and borehole data clearly show that bedrock is not present beneath the foreshrore and barrier dunes from the middle beach to the unnamed creek (at least) in the south. The radar profiles GPR Blue 1a, 2a and 6 (Figures B-2, B-3 and not shown in this report) all show sedimentary reflection occurring to depths at or close to sea level within this area. As previously discussed, the presence of sedimentary reflections also indicates an absence of bedrock. The results show that the Blueys Beach middle to southern coastal system (north of the creek) is vulnerable to erosion. Additionally, Boreholes B.H. Blue 2 and 3 located at the back of the middle and southern Blueys barrier dune also show no bedrock to be present. Here the coastal system comprises varied soft sediments from the surface to below sea level (PWD, 1985).

GPR Blue 7 shows the foreshore south of the unnamed creek at Blueys Beach to comprise a sandy beach backed by a small sandy foredune. A seaward dipping reflection identified beneath the foredune is interpreted as a relic land surface. This surface is likely comprised of indurated silty sands with some minor gravel (as opposed to bedrock), based on the field observations previously discussed and shown in Figure 4-7.

The shore normal radar profile from the southern backshore environment (GPR Blue 1) imaged the subsurface with varying degrees of success (note that only two key sections from this survey are shown in this report, refer Figure B-2 and B-6). A strong "ringing" noise was returned from the shallow depths along a 100 metre stretch or road located approximately 40 m south of GPR Blue 7 (i.e. between E 456,115 m, N 6,420,175 m, and E 546,065 m, N 6,420,100 m GDA94). The ringing radar response is typical of strongly conductive substrate and is interpreted as indicating a highly weathered - clayey bedrock substrate. This type of material was also observed on site from within this area, both from within a natural drainage line and a nearby residential excavation. Highly weathered bedrock is indeed erodible by wave action (Sharples *et. al.*, 2009). Therefore the ~100 metre section of backshore described here along southern Blueys Beach is interpreted as highly weathered rocky substrate and considered to be susceptible to erosion and recession.

In the far southern end of Newman Ave (i.e. immediately south of the 100 m section described previously) the ringing radar response becomes notably reduced (data not presented in this report). This change in radar signal corresponds with a notable change in surface slope (i.e. final approximately 70 metres of Newman Avenue). Together, the change in topography and radar reflection signal is interpreted to indicate geological transition from a highly weathered-clayey rock substrate to a competent (erosion resistant) bedrock slope.

4.2.3.4 Radar Interpretation – North Blueys Beach

A number of reflections returned from the northern Blueys Beach subsurface have been interpreted as forming the bedrock - sediment interface between Boomerang Point and the coastal sedimentary system. These bedrock interpretations include a buried rocky shore platform beneath the foreshore and a moderately sloping rocky surface beneath the backshore dune sediments.

A low amplitude, shallowing dipping reflection was recorded from the far northern corner of the beach from the 50 MHz foreshore survey (GPR Blue 2c), between approximately 750 to 820 metre chainage (Figure B-7). Based on the geographic location and geometric shape of this reflection, it is interpreted as a rocky shore platform buried beneath the beach and dunes. That is, the reflection was recorded adjacent to the steep rocky cliffs and has a form consistent with the morphology of a wave eroded rocky platform (i.e. dips gently away from the adjacent cliffs at an elevation just below mean sea level; Figure B-7). Local borehole data (B.H. Blue 4; PWD, 1985) also shows bedrock at, and just below 0 mAHD beneath the northern barrier dune at Blueys Beach (B.H. Blue 1 and 4; PWD, 1985).

Beneath the northern backshore slopes of Blueys Beach, poorly defined dipping reflections were imaged in the 100 MHz Blueys Beach profiles (GPR Blue 4 and 1b; Figure B-4 and B-5). Those reflections dip away from the adjacent Boomerang Point rocky ridge line and are interpreted as buried bedrock surface which likely forms a buried coastal bluff (i.e. relic cliff) covered by dune sediments. The reflection become lost with depth, however the local borehole data and the northern foreshore GPR results suggest that this rocky surface continues to slopes downwards to around 0 m AHD, where is adjoins a relic (and buried) rocky shore platform.

The data and interpretations described above indicate that land located behind the far northern Blueys Beach only (i.e. the very fringes of Boomerang Point) is underlain by bedrock at an elevation that would withstand wave erosion and recession (i.e. + 4 m AHD). However the large majority of coastal landforms along the northern Blueys Beach foreshore comprise soft – erodible sediments to depths of mean sea level and below. As such, those areas are vulnerable wave erosion and shoreline recession.

4.2.4 Buried Erosion Escarpments

4.2.4.1 Landform Description

As previously discussed (Section 4.1.4) old erosion escarpments can remain in the landscape if they are only partially buried by subsequent beach and dune accretion. A historic photograph from southern Blueys Beach shows a severe 1974 erosion profile where the escarpment had eroded into the barrier dune face. Figure 4-5 shows the escarpment face immediately following the erosion event to be some five to ten metre high along the middle to northern stretch of the beach. The present steep slope of the barrier dune face is likely a remnant feature of this escarpment, although some slumping and minor sand accretion of the profile would have since taken place.

4.2.4.2 Radar Results

The GPR surveys investigating the presence of buried erosion escarpments at Blueys Beach are shown in Figures B-1 and B-4 (Appendix B).

4.2.4.3 Radar Interpretation

As previously described (Section 4.2.2), steep seaward dipping reflections were identified from the middle to northern shore normal profiles and are interpreted as erosion escarpments which include a scarp at the at the foreshore edge of the barrier dune and another beneath the barrier crest. The later scarp reflection may represent an older erosion escarpment and/or the landward boundary between the modern (Holocene) and relic (Pleistocene) barrier dune deposits. The location of the most seaward escarpment reflection described here indicates that the steep slope of the barrier dune face has been formed by a prior erosion event. This is most likely a mid-1970 storm bite.

No erosion escarpments were identified in the southern Bluey Beach radar profile (south of the creek).

5 Discussion

5.1 Ground Penetrating Radar Survey Performance

Ground Penetrating Radar was shown to be an effective technique for investigating the coastal geological system at Blueys and Boomerang Beaches. The radar profiles have identified key geological and landform features, including:

- **Bedrock – sediment interface** at southern Boomerang Beach and northern Blueys Beach, including:
  - Moderate to steep backshore bedrock slopes that extend into the subsurface away from Boomerang Point headland; and
  - A shallowly inclined rocky shore platform located beneath the beach and incipient dunes of in the far north of Blueys Beach.
- Various sandy **beach and dune bedding reflections**;
- Presence of a **buried boulder beach deposit** at the ends of both beaches, but most notably at southern Boomerang Beach;
- **Old-buried erosion escarpments**, including:
  - Beneath the crest of the barrier dunes, which may form the landward limit of the modern (Holocene-age) dune sediments; and
  - At the seaward edge of the barrier dune in northern Blueys Beach and southern Boomerang Beach, which correlate well with the early-mid 1970's storm bite; and
  - Smaller and more recent scarps within the incipient dune.
- **Backshore sedimentary reflections**, including:
  - Landwards dipping bedforms located seaward of the barrier dune crest, resulting from the landward migration of relic transgressive dune; and
  - Channel bedforms from the unnamed creek at Blueys Beach; indicating relic channel migration paths.

In some surveyed locations, a poor signal response was returned. The absence of reflection information does however provide some insight into geological nature of the substrate (i.e. it is conductive), albeit not to any great detail. The strong ringing response from the backshore slopes of southern Blueys Beach was interpreted to indicate a highly weathered – clayey bedrock substrate, resulting from the conductive nature of clays. This interpretation also agreed with local field observations.

Overall, the GPR investigation was deemed to produce good results. The success of the investigation was helped by the combination of factors, including:

- Mostly suitable subsurface conditions;
- The application of multiple antenna frequencies;

- Application of advanced signal processing techniques to enhance the raw data; and
- Correlating the radar results with geological borehole data, field observation and expert geomorphic interpretation of the landscape.

The application of multiple antenna systems, ranging from relatively low (50 MHz) to moderately high (250 MHz) centre frequencies was found to optimise the results of the survey and minimise/avoid the reliance on a single frequency for the geological interpretation of the data.

The 250 MHz data produced detailed reflection surveys of the subsurface, noting fine scale sedimentary features. The dataset was very useful for delineating erosion escarpments and identifying the presence of subsurface boulders.

The 100 MHz data provided good reflections of key bedforms and sedimentary relationships, and helped to distill confidence in the beach and dune interpretations. The greater depth of investigation provided by the 100 MHz antenna was found to be particularly useful in the backshore areas. These data were however quite noisy in some places.

The (unshielded) 50 MHz data provided course reflection data that was difficult to interpret. Data collected from the more urbanised locations were dominated by air-reflections from the above ground objects. In these locations, no reasonable geological information could be discerned. However, 50 MHz data collected form the beach / incipient dunes did successfully image the bedrock interface and retuned reflection from surfaces notably deeper than the other antennas.

The geological information present within the radar dataset was significantly optimised by applying a number of signal processing techniques to enhance the subsurface geological reflections and reduced the unwanted noise. Additionally, the interpretability of the data was greatly improved by correcting the radar profiles for topography and migrating the profiles when required.

The availability of the geological borehole data was also found to be valuable for interpreting and ground truthing the radar data. This was particularly useful within the backshore areas where the sediments comprised relic (Pleistocene-age) dune sands that often returned confused and less well defined reflections.

5.2 Coastal Hazard Definition

Results from the investigation show the vast majority of sandy shoreline at Blueys and Boomerang Beaches to be backed by soft, erodible sediments. Thus with regards to the coastal erosion and recession hazard, all of the foreshore areas encompassed within WorleyParsons (2011) erosion and recession envelopes are comprised of substrates vulnerable to erosion, with the exception of far southern Blueys Beach. Here the GPR results and geomorphic interpretation indicate that the beach backs onto stable rocky slopes.

In the cases of northern Blueys Beach and southern Boomerang Beach, the GPR results identified a buried bedrock surface to dip steeply away from the rocky Boomerang Point and backing ridgeline. Erodible beach and dune sediments overlie this buried bedrock surface. The WorleyParsons (2011) erosion and recession hazard lines do not extend for the full length of erodible shoreline in these areas.

Although ground conditions did not allow the GPR to survey the far northern end of the barrier dune at Boomerang Beach, geomorphic interpretation of the landscape agrees with the alongshore extent of WorleyParsons (2011) hazard definition for this area.

6 Conclusion and Recommendations

The findings of the GPR study provide important detail on the internal structure of Blueys and Boomerang Beach coastal geological systems, including the identification of subsurface bedrock, defining areas where bedrock is absent, and locating buried erosions escarpments. The success of this study has shown GPR to be an effective tool for complementing coastal hazard definition studies.

Combined with the geomorphic interpretation included within this report, the GPR data from this study will enable the existing Blueys and Boomerang Beaches erosion hazard lines (as per WorleyParsons, 2011) to be refined and improved. This should be done by initially defining the spatial extent of potentially erodible coastal sediment bodies and substrate. Using such information, the hazard lines should then be extended into the far corners of the beach and tied into the adjoining bedrock headlands. Additionally, the existing hazard lines should also be removed from the backshore locations identified to comprise stable slopes.

7 References

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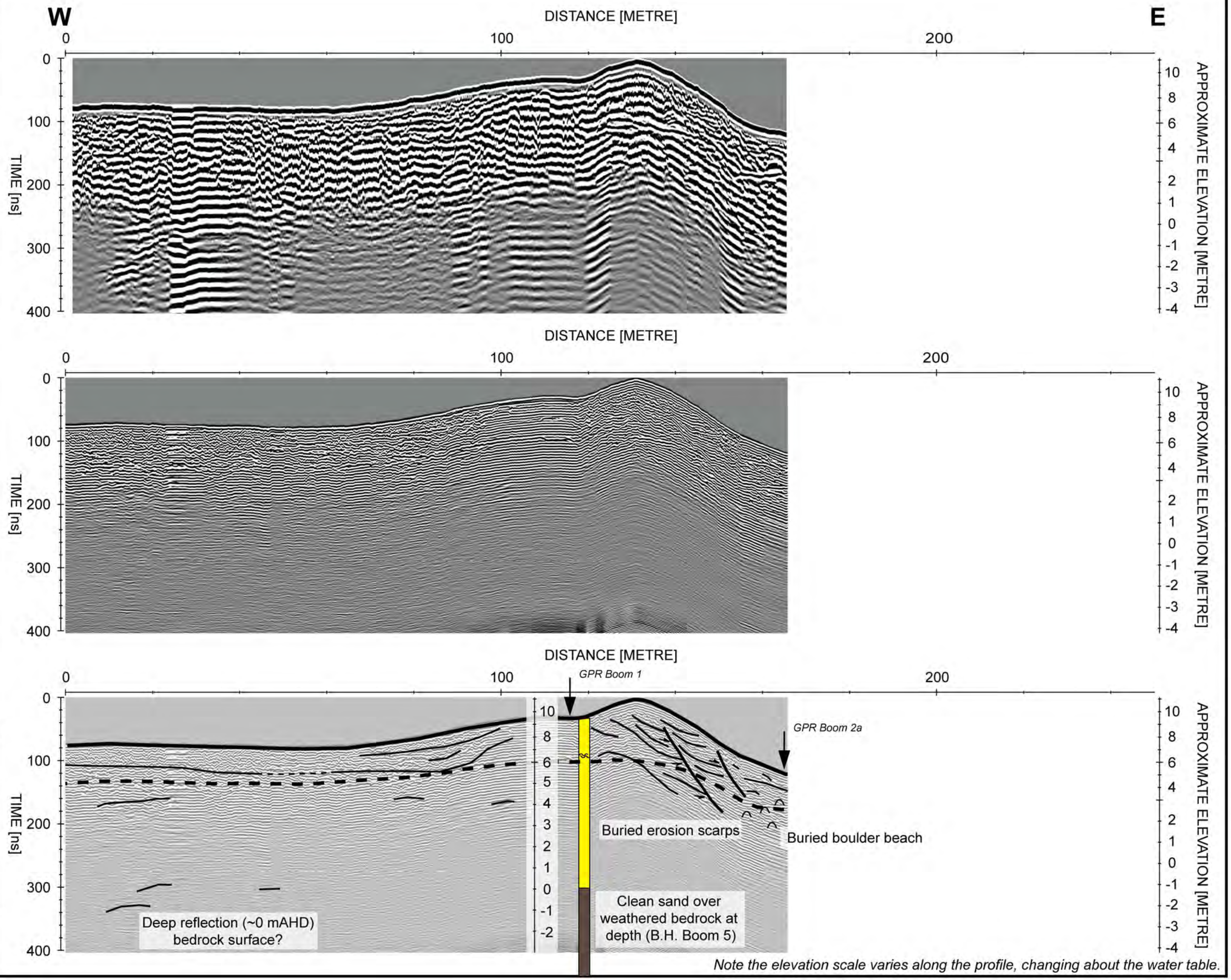
Appendix A Boomerang Beach GPR Drawings

Table A-1 Boomerang Beach Drawing Summary

Figure #	Details
A-1	South Boomerang Beach, backshore to foreshore – shore normal profile
A-2	Far South Boomerang Beach, backshore / barrier dune – shore parallel profile
A-3	Far South Boomerang Beach, foreshore / incipient dune – shore parallel profile
A-4	South Boomerang Beach, foreshore / incipient dune – shore parallel profile
A-5	North Boomerang Beach, backshore to foreshore – shore normal profile
A-6	North Boomerang Beach, foreshore / incipient dune – shore parallel profile



Title:

GPR Boom 6, South Boomerang Beach
Backshroe to Foreshore - Shore Normal Profile

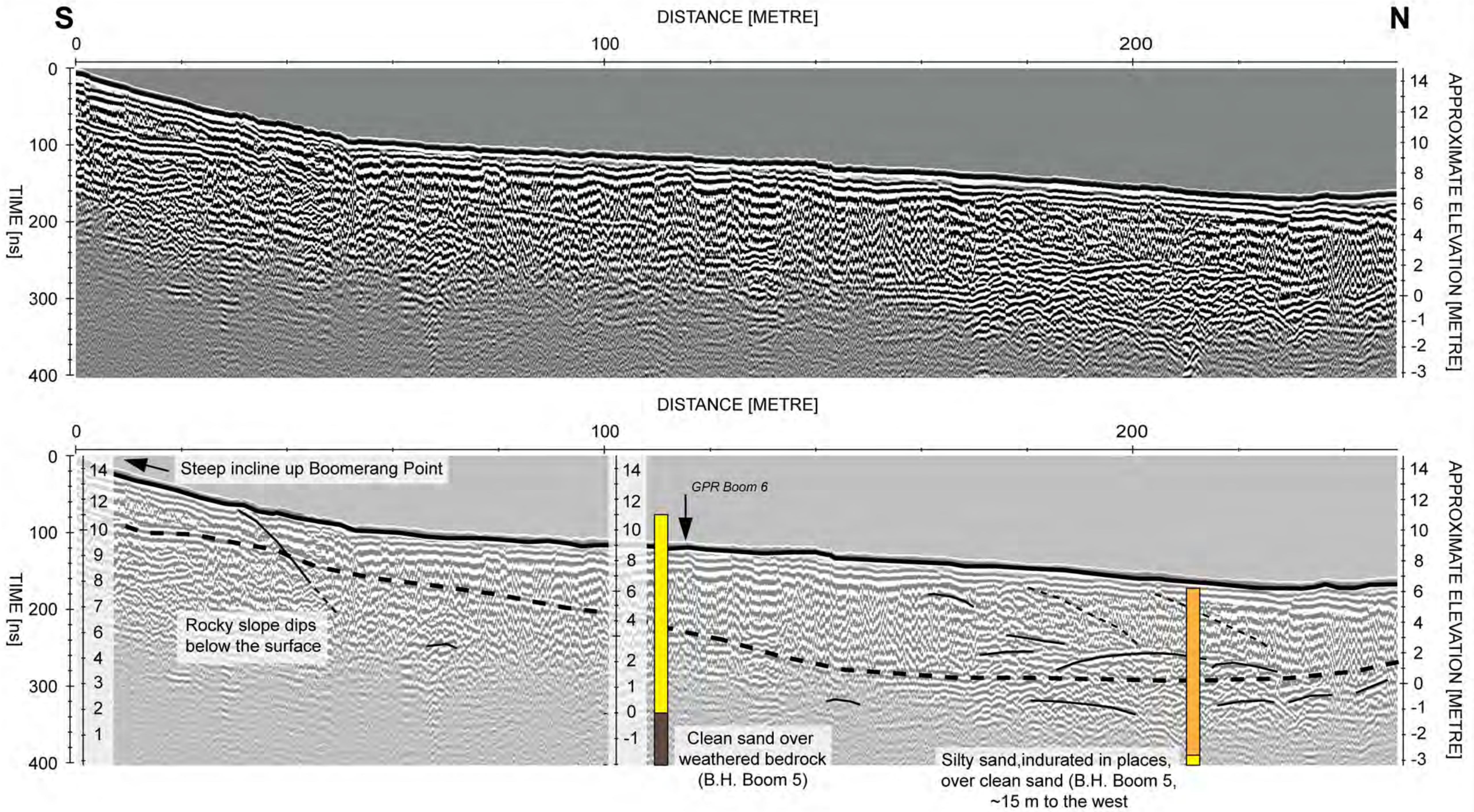
Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: A-1

Rev: A

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_101_Boom6a_Fig_A-1.ai



Note the elevation scale varies along the profile, changing about the water table.

Title:

GPR Boom 1, Far South Boomerang Beach Backshore / Barrier Dune - Shore Parallel Profile

Top: 100 MHz, Middle: 100 MHz, plus line interpretation.
Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

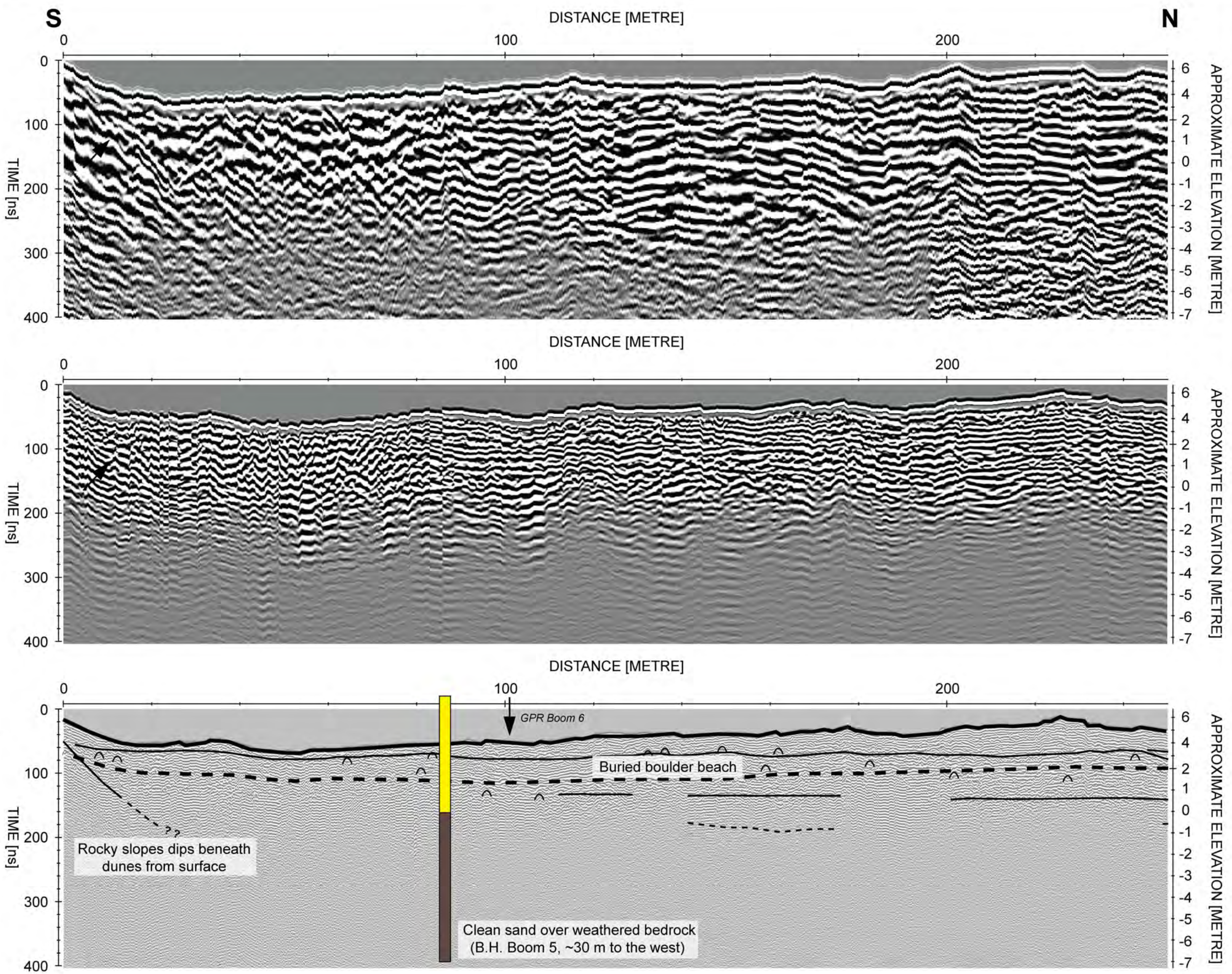
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: **A-2**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_102_Boom1a_Fig_A-2.ai



Title:

GPR Boom 2a (0-250 m), Far South Boomerang Beach Foreshore / Incipient Dune - Shore Parallel Profile

Top: 50 MHz, Middle: 100 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

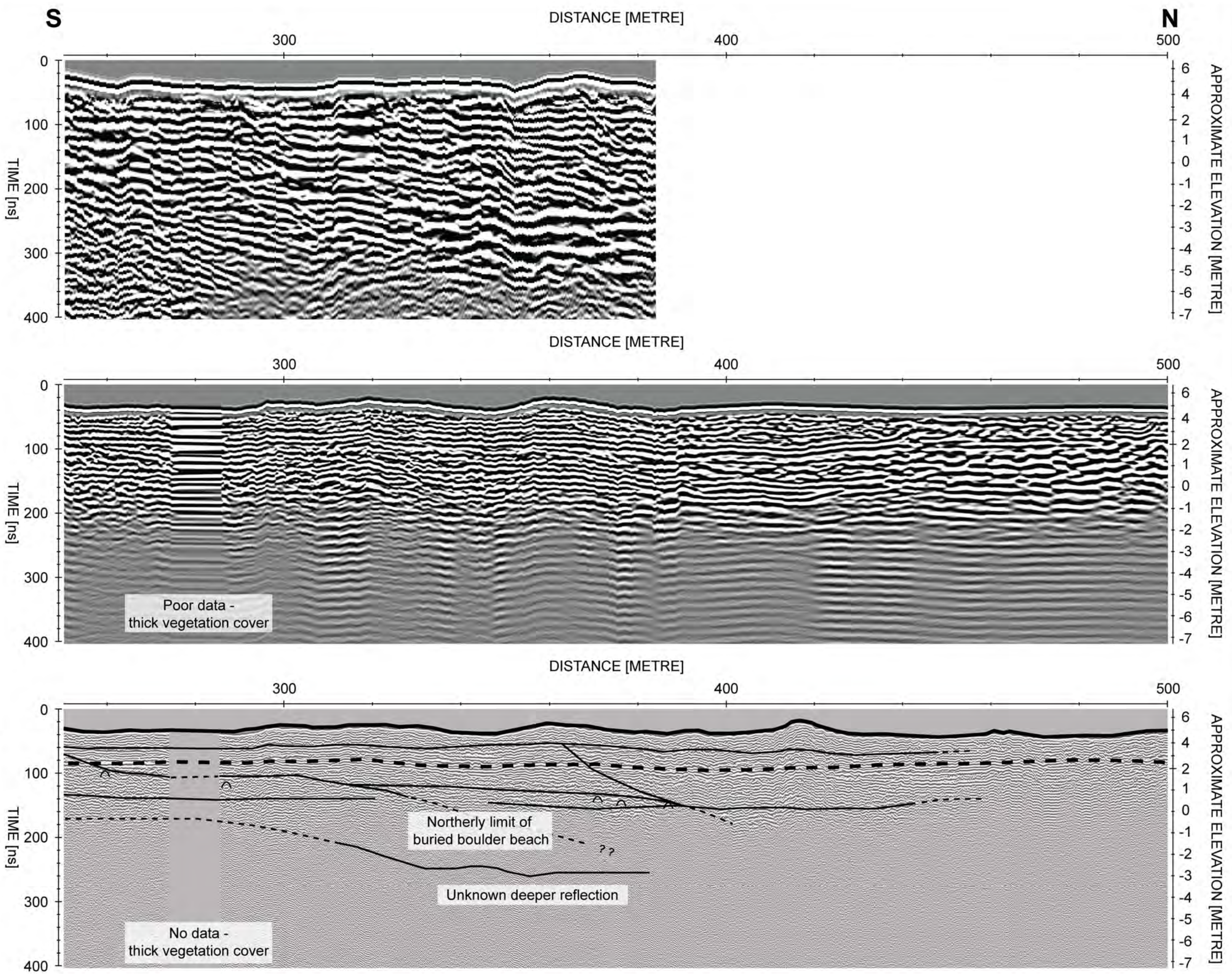
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Indurated silty sand
- Clay
- Bedrock

Figure: **A-3**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_103_Boom2a_Fig_A-3.ai



Title:

GPR Boom 2b (250-500 m), South Boomerang Beach
Foreshore / Incipient Dune - Shore Parallel Profile

Top: 50 MHz, Middle: 100 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

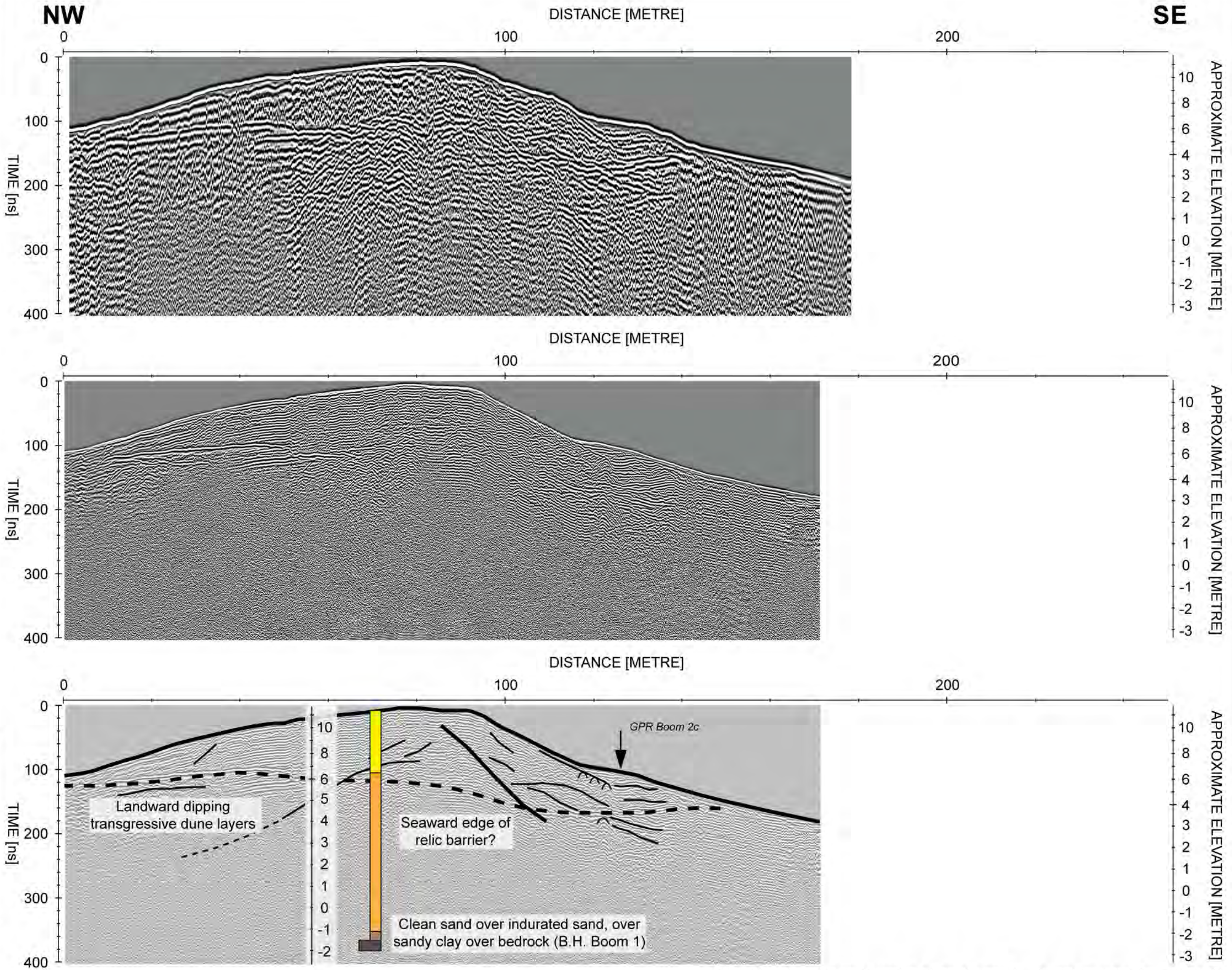
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: **A-4**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_104_Boom2b_Fig_A-4.ai



Note the elevation scale varies along the profile, changing about the water table.

Title:

GPR Boom 3, North Boomerang Beach
Backshore to Foreshore - Shore Normal Profile

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

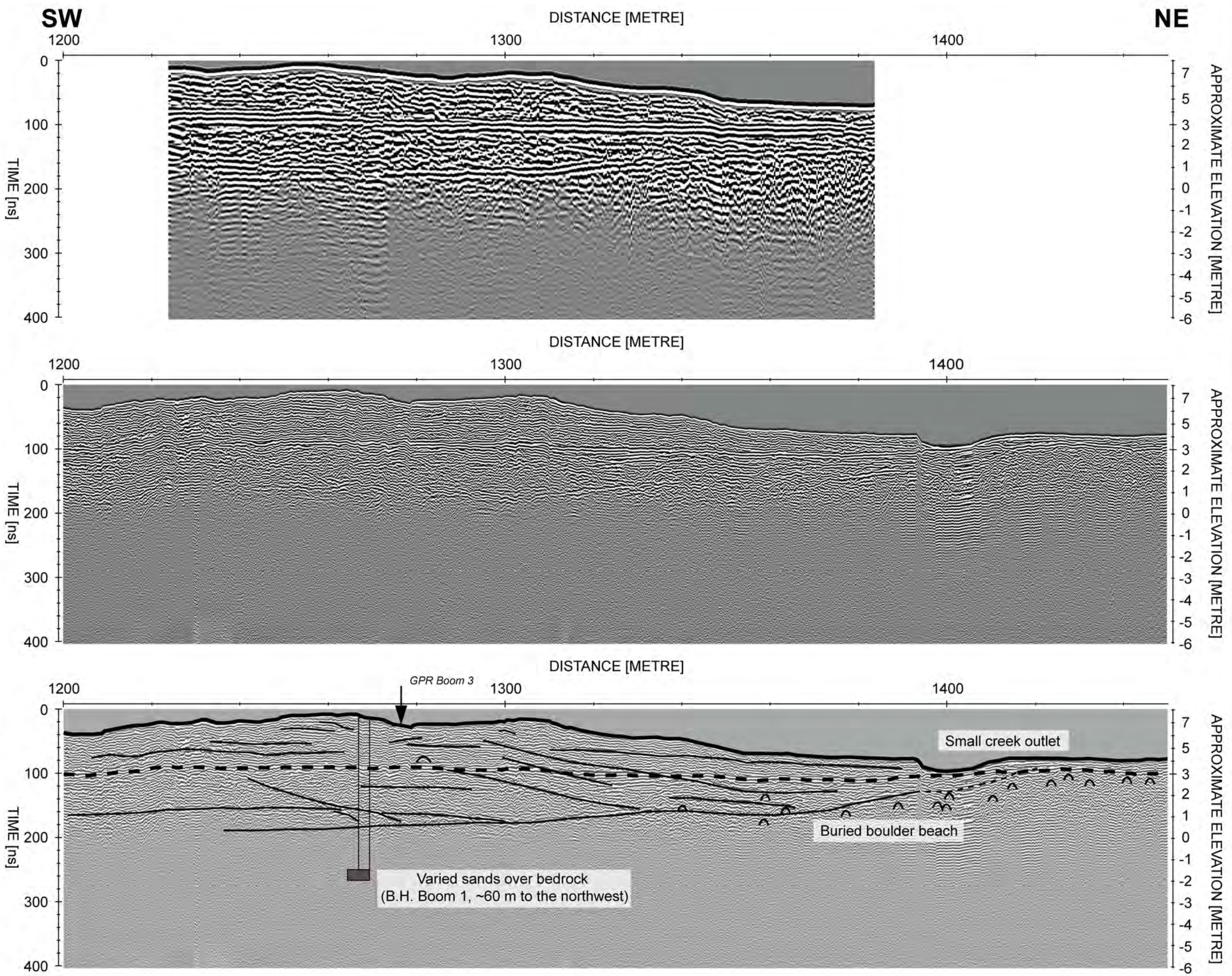
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_105_Boom3a_Fig_A-5.ai

Figure: A-5

Rev: A

BMT WBM



Title:

GPR Boom 2c (1200-1450 m), North Boomerang Beach Foreshore / Incipient Dune - Shore Parallel Survey

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: A-6

Rev: A

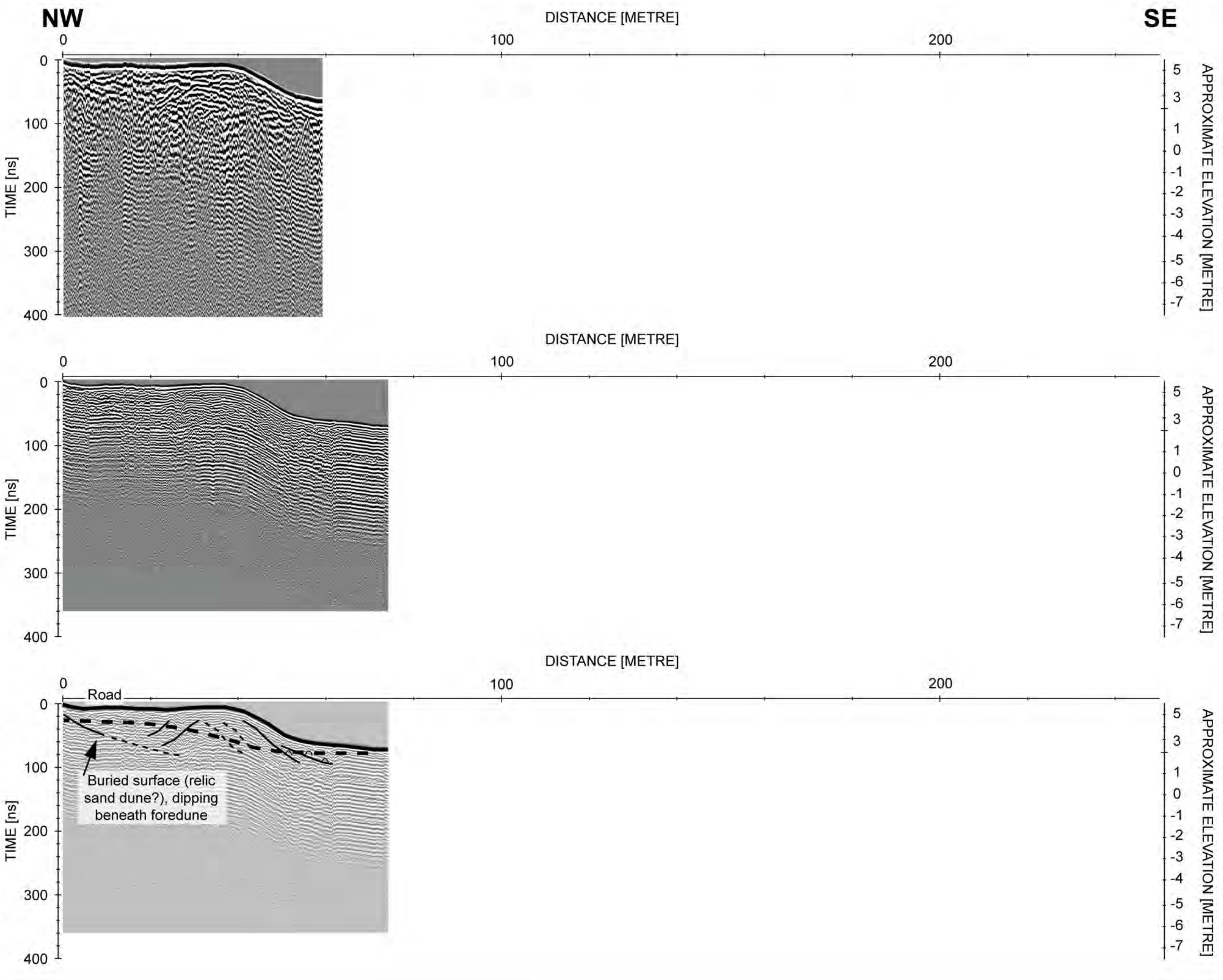
BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_106_Boom2c_Fig_A-6.ai

Appendix B Blueys Beach GPR Drawings

Table B-1 Blueys Beach Drawing Summary

Figure Number	Details
B-1	South Blueys Beach, backshore to foreshore – shore normal profile
B-2	South Blueys Beach, backshore / barrier dune – shore parallel profile
B-3	North Blueys Beach, foreshore / incipient dune – shore parallel profile
B-4	North Blueys Beach, backshore to foreshore – shore normal profile
B-5	North Blueys Beach, backshore / barrier dune – shore parallel profile
B-6	Central Blueys Beach, foreshore / incipient dune – shore parallel profile
B-7	North Blueys Beach, foreshore / incipient dune – shore parallel profile



Title:

GPR Blue 7, South Blueys Beach
Backshroe to Foreshore - Shore Normal Profile

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

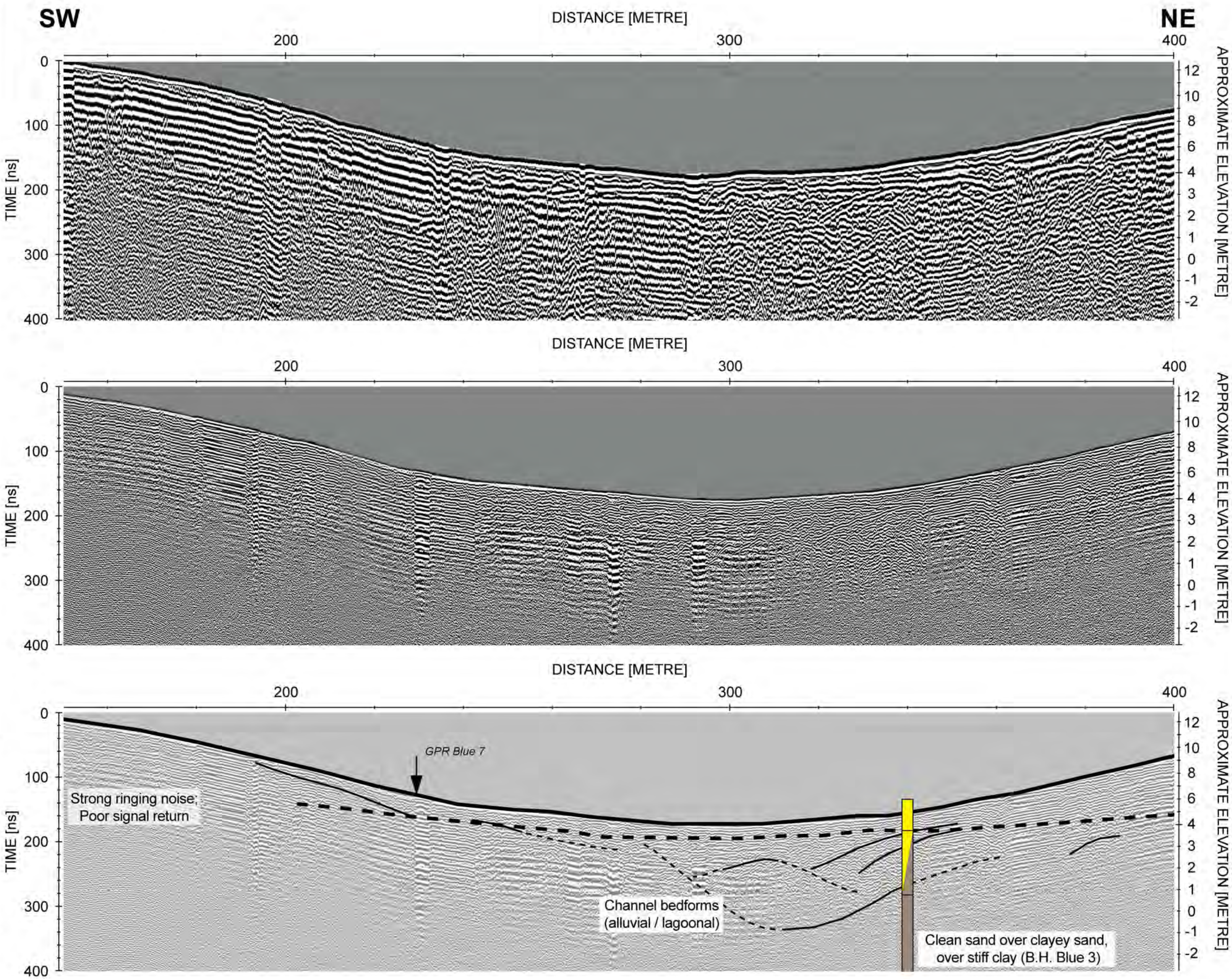
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean san
- Silty sand
- Clay
- Bedrock

Figure: **B-1**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_201_Blue7a_Fig_B-1.ai



Title:

GPR Blue 1a (150-400 m), South Blueys Beach Backshore / Barrier Dune - Shore Parallel Profile

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

Ground surface
Water table
Reflection surface
Poorly defined reflection

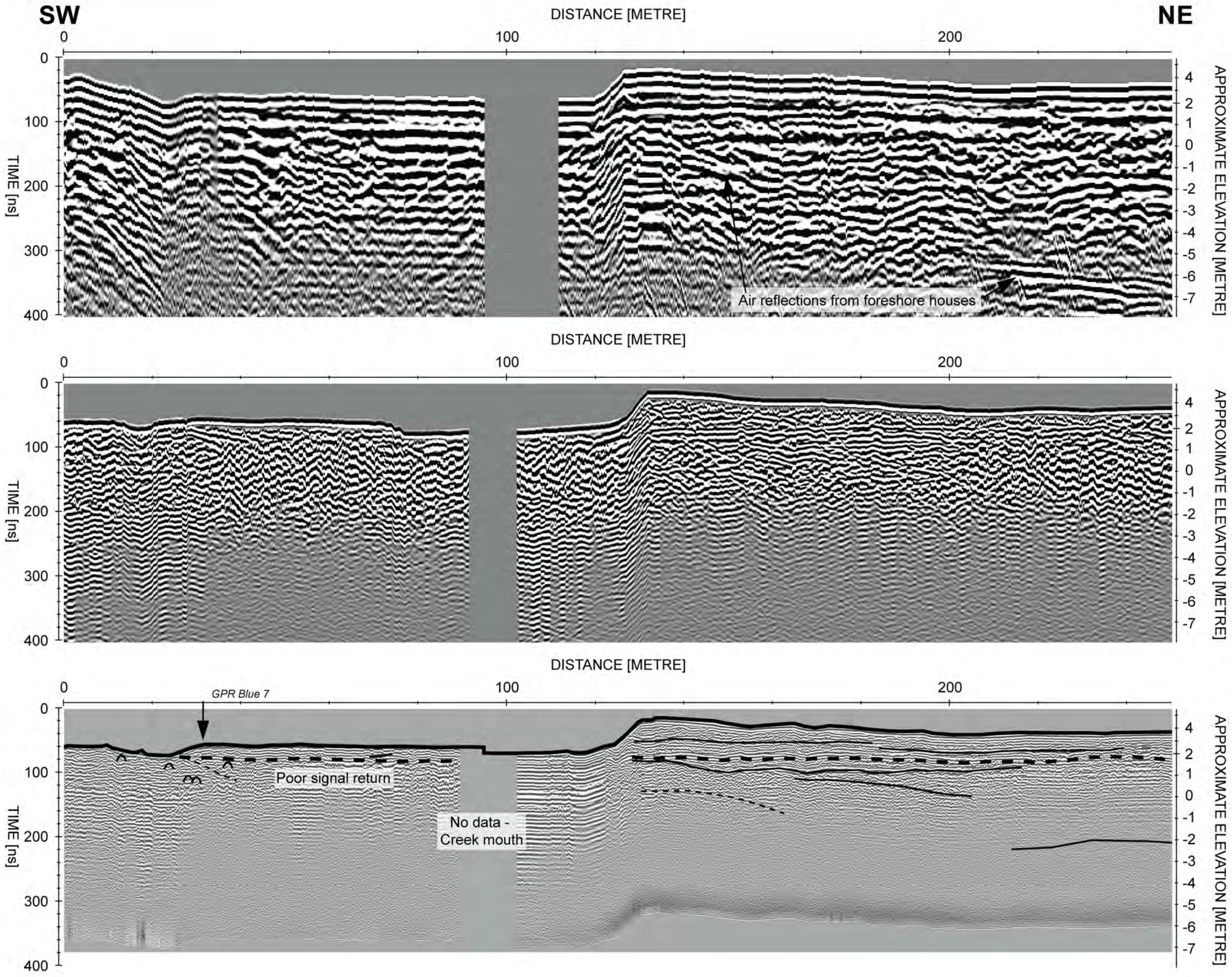
Clean sand
Silty sand
Clay
Bedrock

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_202_Blue1a_Fig_B-2.ai

Figure: B-2

Rev: A

BMT WBM



Title:

GPR Blue 2a (0-250 m), South Blueys Beach

Foreshore / Incipient Dune - Shore Parallel Profile

Top: 50 MHz, Middle: 100 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

Ground surface
Water table
Reflection surface
Poorly defined reflection

Clean sand
Silty sand
Clay
Bedrock

Figure: **B-3**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_203_Blue2a_Fig_B-3.ai

Title:

GPR Blue 4, North Blueys Beach Backshore to Foreshore - Shore Normal Profile

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

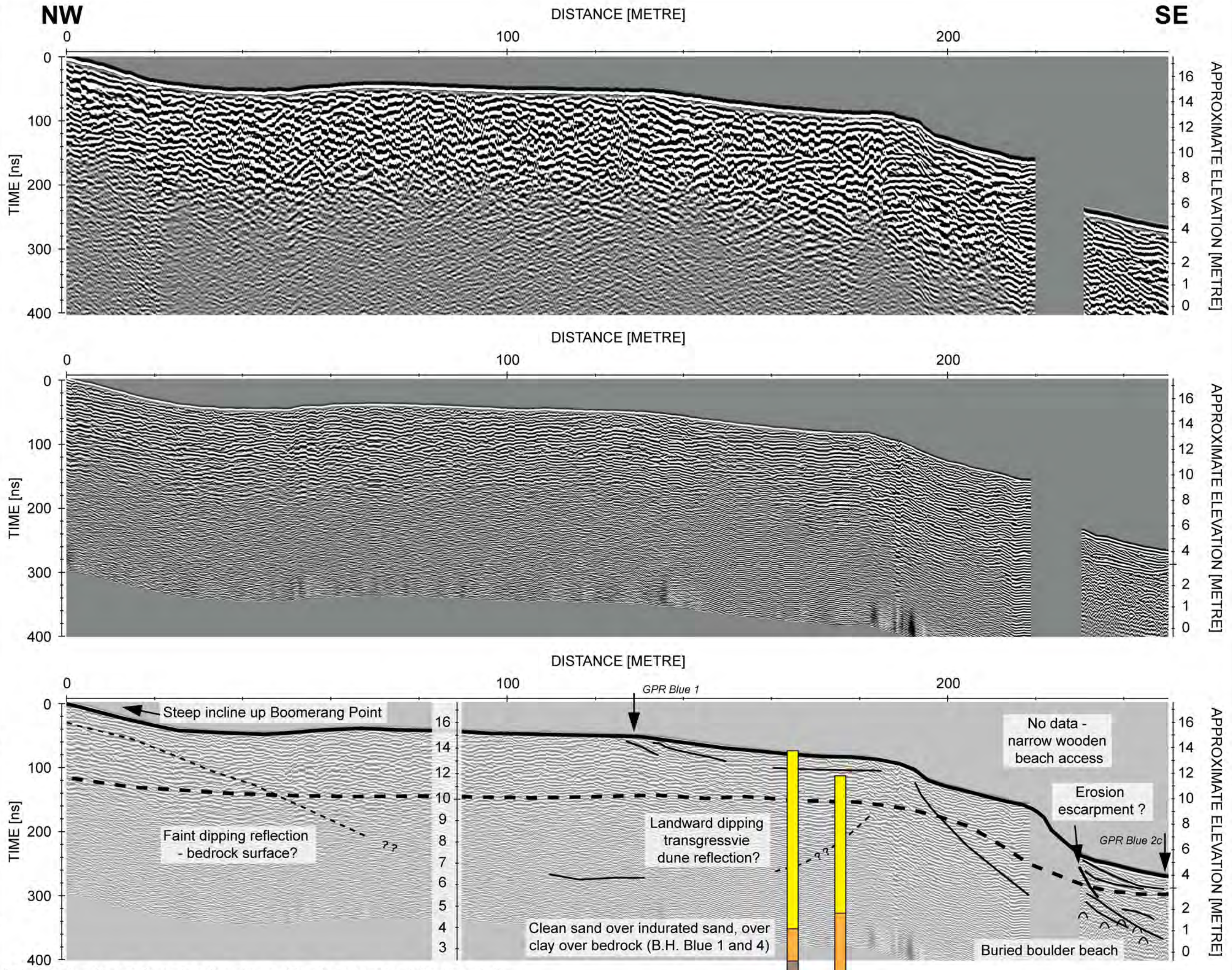
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: B-4

Rev: A

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_204_Blue4a_Fig_B-4.ai



Note the elevation scale varies along the profile, changing about the water table.

Title:

GPR Blue 1b (850-1100 m), North Blueys Beach Backshore / Barrier Dune - Shore Parallel Profile

Top: 100 MHz, Middle: 250 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

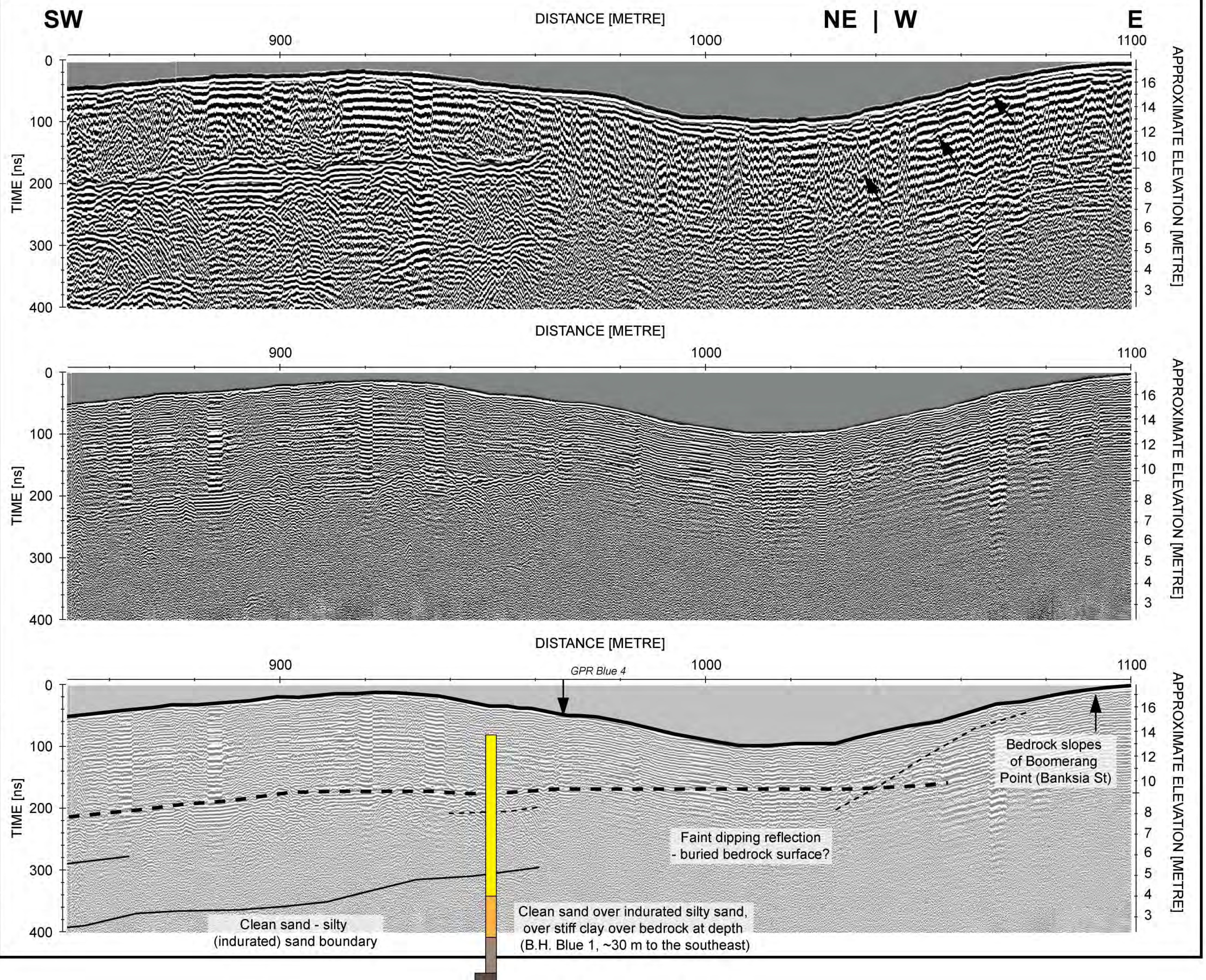
Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_205_Blue1b_Fig_B-5.ai

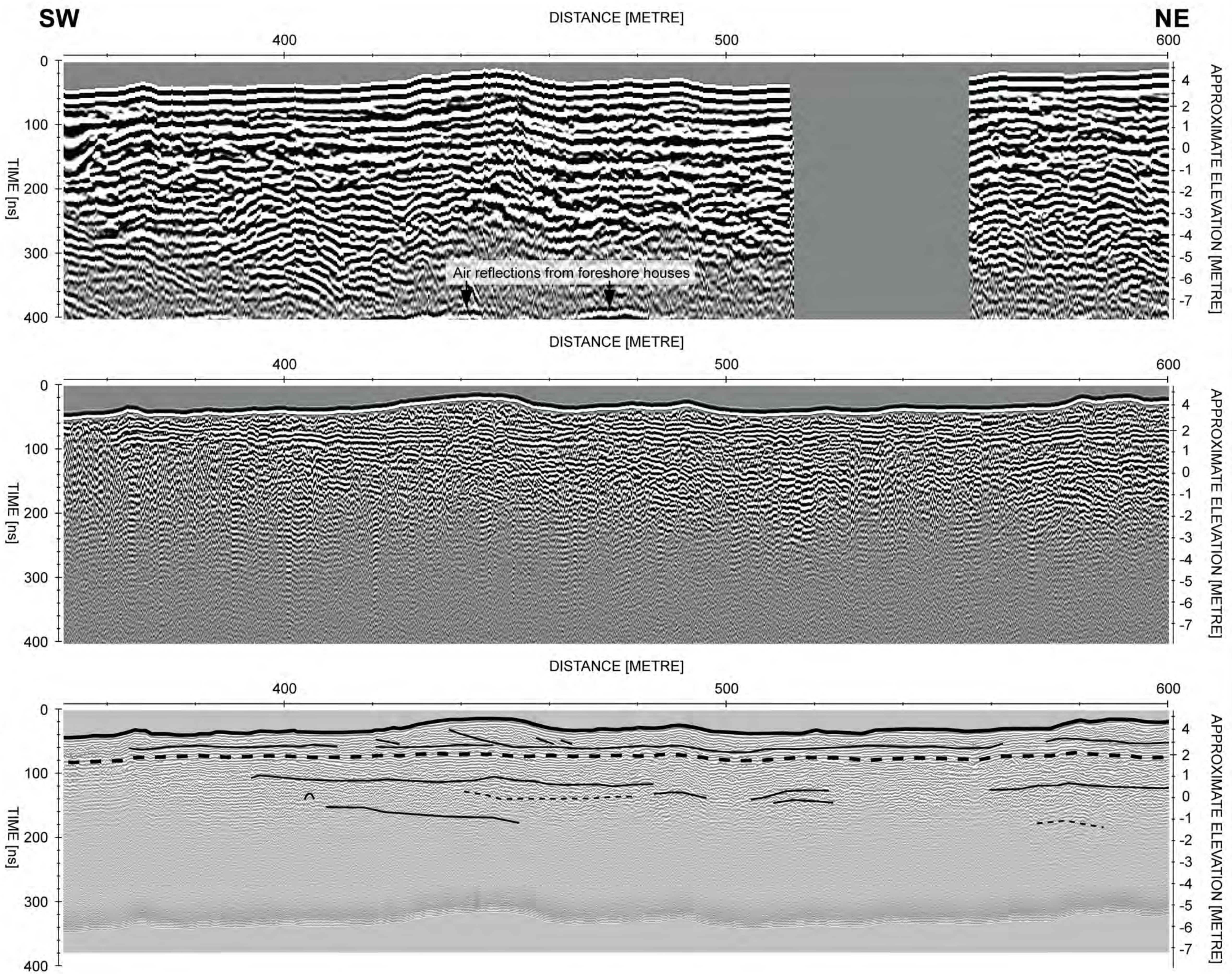
Ground surface
Water table
Reflection surface
Poorly defined reflection
Clean sand
Silty sand
Clay
Bedrock

Figure: B-5

Rev: A

BMT WBM





Title:

GPR Blue 2b (350-600 m), Central Blueys Beach Foreshore / Incipient Dune - Shore Parallel Profile

Top: 50 MHz, Middle: 100 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Figure: **B-6**

Rev: **A**

BMT WBM

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_206_Blue2b_Fig_B-6.ai

Title:

GPR Blue 2c (600-850 m), North Blueys Beach Foreshore / Incipient Dune - Shore Parallel Survey

Top: 50 MHz, Middle: 100 MHz, Bottom: 250 MHz plus line interpretation. Depths approximated using a two layer velocity model, where V1 = 0.1 m/ns and V2 = 0.06 m/ns. Borehole data summarised from PWD (1985).

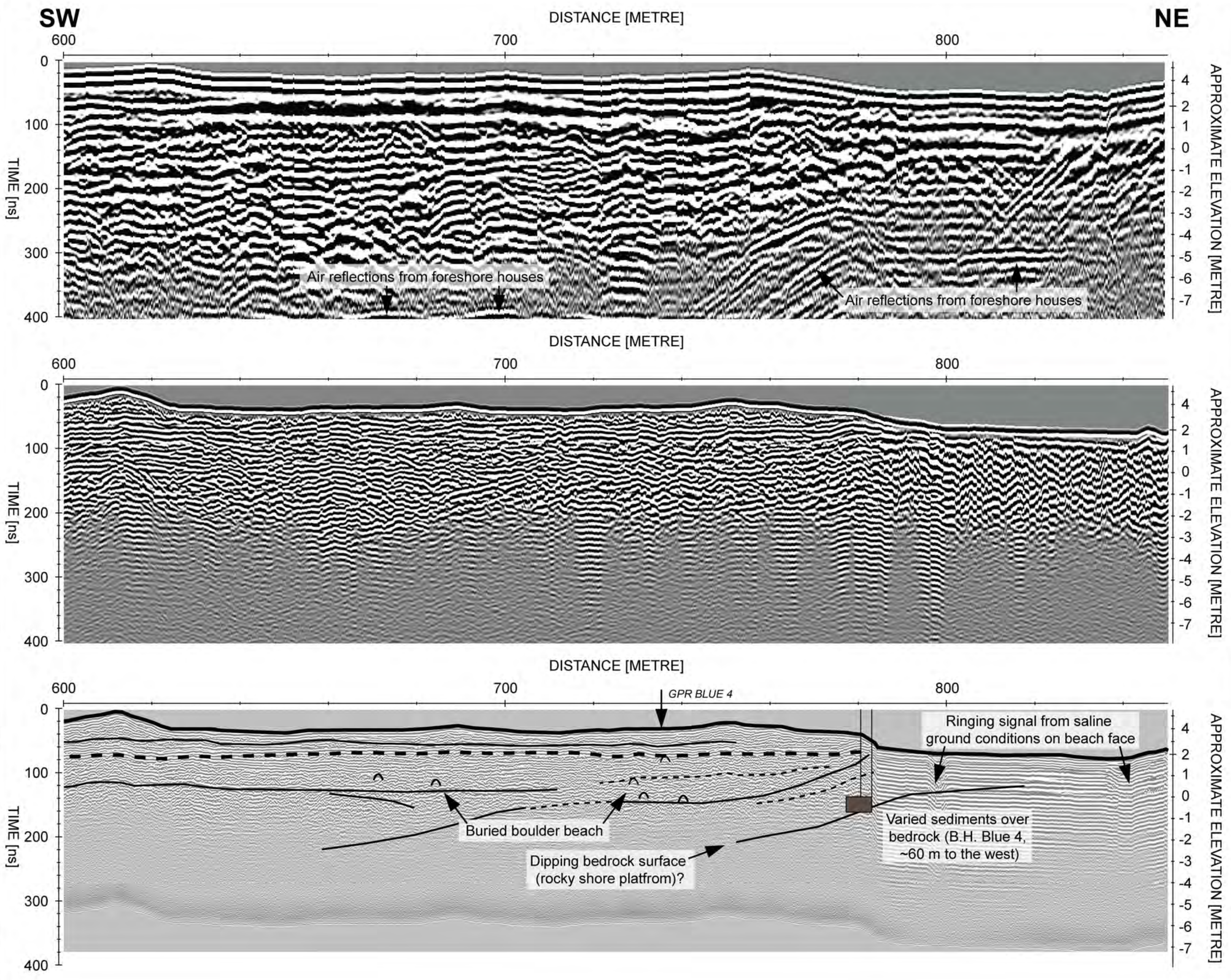
- Ground surface
- Water table
- Reflection surface
- Poorly defined reflection
- Clean sand
- Silty sand
- Clay
- Bedrock

Filepath: K:\N2405_BlueysBoomerangCZMP\GPR_Study\GPR\Drawings\DRG_207_Blue2c_Fig_B-7.ai

Figure: B-7

Rev: A

BMT WBM



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