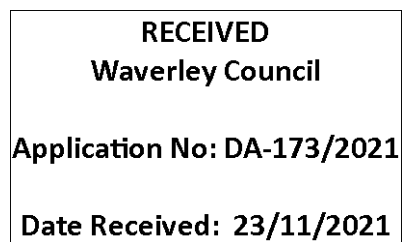


Geoarchaeological Desktop Assessment

Bondi Surf Club, Bondi Beach, NSW

Report to
Lockhart-Krause Architects



Down to Earth Geoarchaeological Services
22 November 2021

Acknowledgement

Down to Earth Geoarchaeological Services acknowledges Traditional Owners of Country throughout Australia and recognises their continuing connection to lands, waters and communities. We pay our respect to Aboriginal and Torres Strait Islander cultures and to Elders both past and present.

We support the Uluru Statement from the Heart (<https://fromtheheart.com.au/uluru-statement/the-statement/>) and the From the Heart campaign for a Voice to Parliament enabled by the constitution (<https://fromtheheart.com.au/>).

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Document Control

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Executive Summary

This geoarchaeological desktop assessment investigates the potential archaeological (scientific) sensitivity of an open area on the north side of Bondi Surf Club, Bondi Beach, NSW, and was commissioned by Lockhart-Krause Architects. The study area is located north of Bondi beach and east of Bondi Pavilion, the Pavilion being located approximately in the centre of the now truncated foredunes of the embayment above the beach itself. The study area is currently obscured by temporary amenities and building additions that will be demolished.

This assessment deciphers the available Quaternary geological mapping for the study area and analyses the relevant archaeological, geoarchaeological and geotechnical data from previous heritage assessments of Bondi Beach from a geoarchaeological perspective. It assesses the nature of the stratigraphic record on the study area and its potential to retain archaeological and palaeoenvironmental signatures (objects, archaeological features or proxy data) in potential archaeological deposits and identifies non-archaeological sediments such as earthworks or construction fills.

One of the intended uses of this desktop assessment will be to inform an archaeological cultural heritage assessment report that will subsequently guide the client in terms of their statutory requirements under the *NSW National Parks and Wildlife Act 1974* and *Heritage Act 1977*.

The report identified the following stratigraphic units (Figure 2.16):

- A basal sand buried several metres below current ground surfaces, potentially representing the Pleistocene bedrock-mantling dune geological formation (Qpbdr). These deposits are potential archaeological deposits (PAD) with high scientific values because of their potential to retain in situ archaeological and palaeoenvironmental signatures. The proposed impacts do not extend into this stratigraphic unit.
- A deposit of medium to very dense sands sit above these basal sands which have been assigned (stratigraphically) to the Early and Mid-Holocene, making them part of the Holocene bedrock mantling dune geological formation (Qhbd). Again, these deposits are potential archaeological deposits (PAD) with high scientific values because of their potential to retain in situ archaeological and palaeoenvironmental signatures. Proposed impacts will impact these deposits: see recommendations.
- These sands are subsequently overlain by a very loose to stiff silty sand and silty clay deposit that suggests an inter swale depositional environment (lagoon?) in the southern half of the study area. These deposits are unlikely to retain archaeological signatures, i.e. they are not PAD, but are important because they have a high potential to retain palaeoenvironmental signatures that can inform us about climate, hydrology and vegetation patterns. The proposed impacts do not extend into this stratigraphic unit.
- Two final episodes of dune formation are represented by a very loose to loose silty sand in the northern half, and a medium dense sand to the south superimposed over the inter swale deposit. These deposits are also part of the Holocene bedrock mantling dune geological formation (Qhbd). As such, these deposits are PAD with high scientific values because of their potential to retain in situ archaeological

and palaeoenvironmental signatures. Proposed impacts will impact these deposits: see recommendations.

- The final phase of dune building is truncated by the post-1788 (Anthropocene) deposits of the early 1800's through to the modern period, and are represented by landscaping earthworks, construction fills, services and building footprints. These deposits are highly disturbed and are assessed as non-PAD. Proposed impacts will impact these deposits: see recommendations.

The recommendations are based on the conclusions of the geoarchaeological assessment. These are:

1. The geoarchaeological assessment has concluded that there is scientific evidence for PAD and an archaeological testing program may be warranted. However, due to site constraints with the study area currently obscured by temporary amenities and additions, a staged approach is required for subsequent investigations. See schedule below (Section 3.6).
2. Therefore, we recommend that a geoarchaeological investigation is undertaken with the objective of recovering undisturbed boreholes, since there is a high probability that PAD may be located several metres below current ground surfaces, and traditional archaeological sampling techniques are unsuited to these conditions. This stage of works is planned for March 2022.
3. Stratigraphic, chronological and palaeoenvironmental analysis will need to be carried out on the deposits recovered from the boreholes to scientifically assess the preliminary hypothesis and ascertain whether the deposits are in fact PAD or non-PAD: see schedule below (Section 3.6).
4. Generating a 3D stratigraphic model based on the scientific analysis will provide the framework for informing where and how PAD can be assessed during an archaeological testing program. Conversely, the scientific analysis of the deposits may conclude that archaeological test excavation is not warranted, for example because all the deposits below fills pre-date the Aboriginal settlement of Australia.

1.0 Project Overview

1.1 Introduction

This geoarchaeological desktop assessment investigates the potential archaeological (scientific) sensitivity of an open area on the north side of Bondi Surf Club, Bondi Beach, NSW. The report was commissioned by Lockhart-Krause Architects (henceforth 'client'). The study area is located north of Bondi beach and east of Bondi Pavilion, the Pavilion being located approximately in the centre of the now truncated foredunes of the embayment above the beach itself (Figures 1.1-1.2 and Plate 1). The study area is currently obscured by temporary amenities.

This assessment deciphers the available Quaternary geological mapping for the study area and analyses the relevant archaeological, geoarchaeological and geotechnical data from previous heritage assessments of Bondi Beach from a geoarchaeological perspective. A cross section adapted from the geotechnical investigation of the study area is presented as a 2D stratigraphic model on the nature of potential archaeological deposits (PAD) and non-archaeologically sensitive deposits (e.g. construction fills, concrete and modern paving, or landscaping). This is accompanied by a simple geoarchaeological site formation model to illustrate how the Bondi area has changed over the last 30,000 years, and the knock-on effects that those – largely geomorphic - processes may have had in relation to the potential nature, detectability, location (depth and extent) and preservation of archaeological, stratigraphic and palaeoenvironmental signatures within the footprint of the proposed basement (Figure 1.2).



Plate 1. 31st October 2021, at the rear (northern side) of Bondi Surf Bathing Club. Due to site constraints with the study area currently obscured by temporary amenities and additions, a staged approach is required for subsequent investigations. See sequencing schedule.

One of the intended uses of this desktop assessment will be to inform an archaeological cultural heritage assessment report that will subsequently guide the client in terms of their statutory requirements under the *NSW National Parks and Wildlife Act 1974* and *Heritage Act 1977*.

Bondi Surf Club Desktop Geoarchaeological Assessment



Figure 1.1. General location of study area (Source: Imagery data © Department of Customer Service 2020).

Bondi Surf Club Desktop Geoarchaeological Assessment

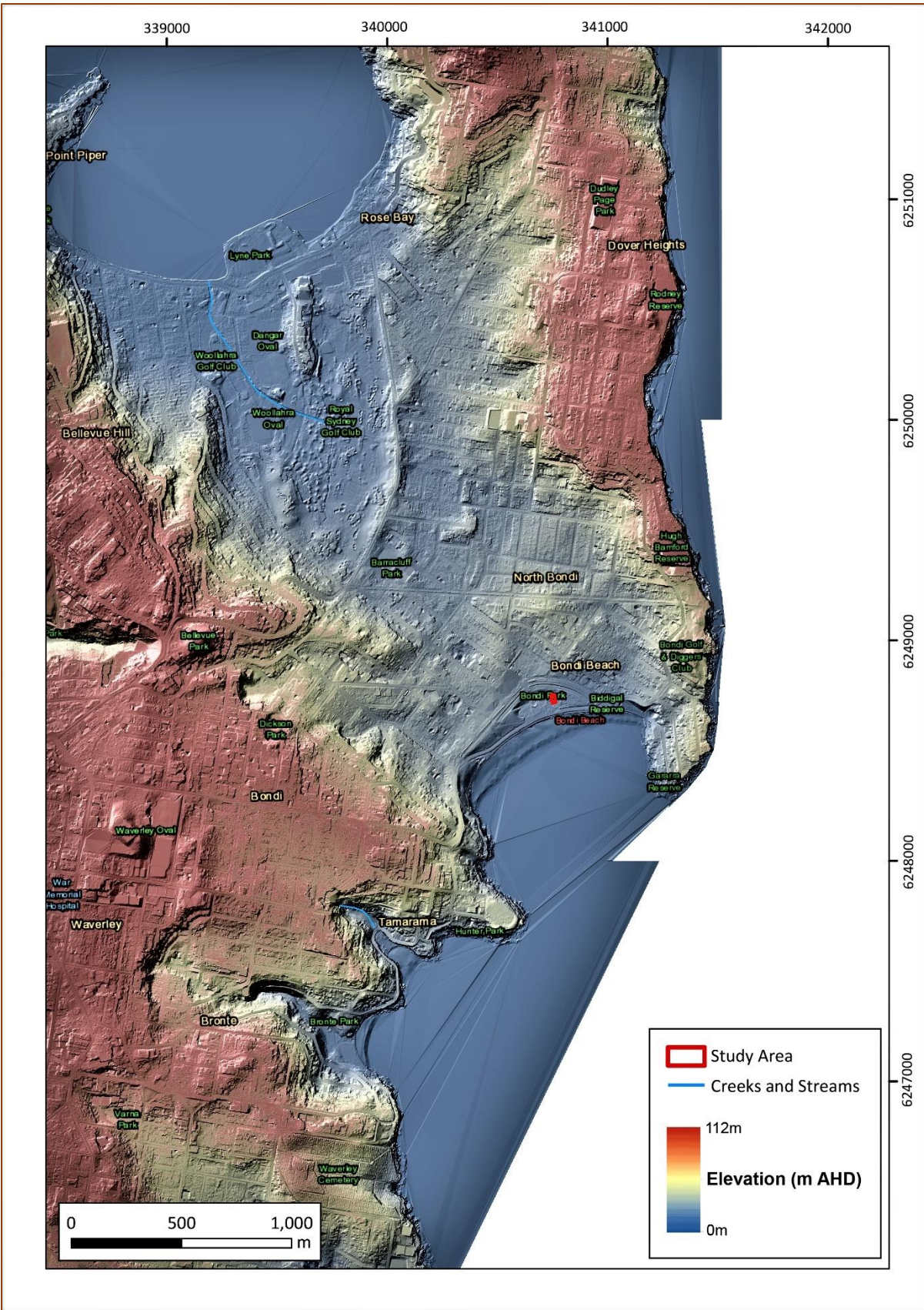


Figure 1.2. DEM map of study area and surrounds (Source: Imagery data © Department of Customer Service 2020).

1.2 The Geoarchaeological Approach

'It is probably the only consensus in archaeology that stratigraphy is 'the jugular vein of archaeological practice'...Stratigraphy has many definitions and is defined here as the spatial and temporal arrangement of depositional units. Regardless of the wording, it provides the framework of reconstructing the history of a site. Stratigraphic units, layers, features, cuts, or strata – also called context or locus according to different archaeological schools of thought – are made of sediments that are the product of natural processes and anthropogenic activities, and are deposited on the surface of the earth. Archaeological deposits – those that contain artefacts and anthropogenic products – are thus by their very nature forcibly part of the archaeological record. In order to interpret the archaeology of a site correctly, it is a prerequisite to understand how stratigraphy is built and how the strata are formed (Karkanos and Goldberg 2019: 1).'

Geoarchaeology provides a scientific platform on which to make predictions on the presence or absence of potential archaeological deposits (PAD) and inform on the probability of in situ (in place) verses secondary (reworked) contexts. It includes spatial parameters that trace the depth and extent of contexts, as well as quantifying the volume and 'accessibility' of the deposits for archaeological testing and salvage, e.g. are the PAD under two metres of fill? This approach was encapsulated in the *Eastern Creek Geoarchaeological Model and Strategy: Assessment, Interpretation and Strategic Conservation of the Archaeological Resource* (Barham 2008), which provided a theoretical and practical framework for geoarchaeological investigations. It identified key deficiencies in archaeological research designs:

- *'Very limited integration of research on regolith, landscape change and Quaternary dating into the design, execution and interpretation of results from archaeological studies....*
- *Few attempts to develop local palaeoenvironmental records specific to known areas of past occupation (and of high significance) on the Cumberland Plain, eg. relating to past woodland, floodplain ecology, resources, stability of water regimes.*
- *Inadequate archiving of stratigraphy and soils relating to archaeological contexts.*

A critical deficiency is that while lithic artefacts are being retrieved, as sampled assemblages, from the landscapes ahead of destruction by development, no comparable effort is being made to conserve samples of the past landscape contexts of these materials (i.e the soils, stratigraphy and proxy data therein contained). The inevitable, and obvious, consequence of this is that while the archaeological mitigation studies continue to justify the retrieval of stone artefacts within broader frameworks such as "sampling past Aboriginal landscapes", or understanding "taphonomy", or "defining past palaeoeconomy or past habitats" or understanding the actions represented by artefacts in ecological terms, virtually no attempts are being made to acquire suitable data to do these things. The soils and stratigraphic contexts are destroyed by development (Barham 2008: 131).'

Unfortunately these issues became entrenched with the introduction of the *Code of Practice for Archaeological Investigation of Aboriginal Objects in New South Wales* (DECCW 2010).

The code is focussed on random rather than targeted sampling grids with the preferred sample trench size between 0.5m²-1m² preferably excavated in spits of 5, 10 or 20 cm, as opposed to being guided by the actual stratigraphic units present. Spits are generally excavated to a maximum depth of 1.2 m below surface levels, which is the deepest one can excavate without shoring. In the absence of geoarchaeological investigations - on the vast majority of 'archaeological' testing programs - it is fairly obvious that the code's approach is not scientific but relies both on completely random sampling points and sampling units. This is problematic from an Aboriginal heritage risk perspective for clients, since investigations rarely consider or sample the archaeological potential of deposits below depths of 1.2 m.

Thus, a geoarchaeological approach has several advantages over the traditional archaeological approaches undertaken by heritage consultants. The *Eastern Creek Geoarchaeological Model and Strategy* provided 'a roadmap to recovery for archaeological research designs' in terms of the NSW Government draft model for new Aboriginal Culture and Heritage laws proposed in 2018. It also provides key archaeological, theoretical and methodological considerations that must be built into archaeological research designs if we are to ascribe ourselves the title of 'archaeologists,' rather than 'antiquarians' as a profession.

1.3 Terminology

As a technical geoarchaeological report, the use of terminology from the earth sciences and archaeology is necessary, but the myriad of terms used can be confusing. A brief review of terminology is presented here to facilitate clarity on some of the vocabulary, and the following section provides a guide to the conceptual framework of geoarchaeology.

Sediments have a dynamic history that involves erosion, transport and deposition over an area or landscape (Goldberg and Macphail 2006: 46). In contrast, soils require 'stable' conditions to form in situ through various weathering (chemical and physical) and biological processes, collectively termed pedogenesis. Archaeological deposits are therefore by definition sediments because they have accumulated through sedimentary processes, some or all of which are anthropogenic (Goldberg and Macphail 2006; Stein 2001; Barham 2008). They can however become subject to soil forming processes. For example, stone artefacts and a hearth can be bioturbated from the surface of a topsoil into the subsurface matrix.

Sediments come in three types: clastic, chemical and organic. Clastic sediments are the most common and the matrix comprises fragments of rock, other sediment or eroded soils, but can also include volcanoclastic materials (volcanic ash, blocks, bombs and pyroclastic flows) in the definition (Goldberg and Macphail 2006: 11). Chemical sediments form through precipitation and diagenesis of mineral suites and biological sediments are composed of organic materials, usually plant matter, for example peat deposits in wetlands (ibid: 13). Clastic sediments are the most common sediments that archaeologists will deal with, and they can be composed of any combination of clast sizes from (in increasing size) clay, silt, sand, gravels, cobbles, stones and boulders, where the field texture of soils and sediments is determined from the material below 2mm in size, i.e. coarse sand, the next size class up being fine gravels (McDonald and Isbell 2009: 161-163).

There are also a variety of terms that archaeologists and earth scientists use to identify deposits that are the result of post-1788 land management practices. These practices have exacerbated and amplified geomorphic processes and are responsible for vast amounts of reworked sediments in the Australian landscape today (Allen 2013; Butzer and Helgren 2005; Cook 2019; Eyles 1977; Mactaggart et al 2007). Alluvial (deposits laid down by rivers or during flood events that burst a rivers bank) and colluvial (deposits moved by water or gravity downslope) deposits have variously been described as post settlement alluvium or colluvium, and legacy sediments (Allen 2013; Lawrence and Davies 2018). The term legacy sediment is preferred:

'Legacy sediment is primarily alluvium [and colluvium] that was deposited following human disturbances in a watershed. The disturbance may have been in the form of deforestation, plowing [sic] agricultural land, mining, or other land-use changes. In North America and Australia, legacy sediments are ubiquitous and represent episodic erosion in response to the colonization of land by European settlers who introduced Old World land clearance technologies (e.g. steel tools and plows [sic] pulled by draft animals) and export economies. In these settings, legacy sediments are often described as post-settlement alluvium (PSA), which may cover entire floodplains and bury the presettlement soil with a thick mantle of relatively young stratified sediment (Allen 2013: 19).'

Legacy sediments are represented in various forms across Bondi Beach. They include a range of deposits such as redeposited fills created by historical and modern earthworks or landscaping, to dunes reworked by historical processes associated with changing land use such as grazing or construction. These land use changes began with grazing of livestock on the dunes in the 1800's. Driven by the availability of freshwater represented by the (now drained and infilled) lagoons, grazing was the initial land use, but after the drainage of the wetlands (lagoons) began in the 1880's and the construction of the Bondi Ocean Outfall Sewer in 1883, the urbanisation in the Late 19th and 20th Century's took over and either destroyed or buried the natural landscape of 'Bondi Beach,' that is, the natural geomorphological character of the landscape. These activities have buried the pre-1788 landscapes, but they have not destroyed them. These historical activities have however made the pre-1788 geological formations and their resident archaeological and palaeoenvironmental signatures very difficult to examine or sample (Steele and Czastka 2020).

Soil horizons are layers of soil that are approximately parallel to the land surface and have morphological properties that are different from layers above or below them (McDonald and Isabel 2008). Soils have their own form of notation and are classified according to the degree of weathering (National Committee on Soil and Terrain 2009). The topsoil is identified as an 'A' horizon: it is the zone within which all the biological activity is confined and is stratigraphically positioned as the land surface. In a normal soil sequence, the A horizon is underlain by a more weathered and typically more clayey subsoil: these are classified as B horizon soils. The final horizon in a typical soil profile is the C horizon: this represents the weathering bedrock on residual soils or the weathering parent sediments in a transported soil. Soil horizons can also be subdivided themselves, for example A1 or A2. Finally, there is in addition a special category of soils known as palaeosols, and this simply refers to the fact that these soils formed under different climatic conditions than those of today. An example would be a soil formed during the drier, windier conditions of the Last Glacial Maximum (c.27-17,000 years ago). Three types of

palaeosols are recognised: buried, relict (i.e. it forms part of the present-day ground surface), and exposed (i.e. erosion has stripped the overlying deposits to expose the palaeosol beneath).

The terms Interglacial, Glacial, Stadial and Interstadial are also used in this report. These terms relate to climatic systems that have prevailed in the past. Glacial refers to a period of colder, drier conditions with extensive land ice and lower sea levels, an Interglacial represents a warmer period of climate such as today (the geological term being the Holocene Interglacial for our current period or 'Epoch'), a Stadial refers to cooling conditions and increase ice mass in a Glacial, and an Interstadial refers to a relatively short-lived period of time during an ice age where climate becomes warmer. For most of the last 2.58 million years – the geological term being the Quaternary Period – ice ages have dominated Earth's climatic systems and concomitantly, landscapes were quite different than today. A good example of this is that Tasmania and Papua New Guinea were part of the mainland during the last ice age, a period known as the Late Glacial Maximum or 'LGM.'

All descriptions and terminology in relation to soils and geomorphology follow the Australian Soil and Land Survey Field Handbook (National Committee on Soil and Terrain 2009). Sediments are described using standard Quaternary logging procedures (Jones et al. 1999). Geological nomenclature and chronology follow the International Chronostratigraphic Chart (Cohen et al 2013). This ensures that the data is consistent with national and international standards and the conclusions can be verified by any earth scientist and/or geoarchaeologist.

1.4 Conceptual Framework

Establishing a conceptual framework is important to facilitate future discussions on framing appropriate research questions and the range of methods that could or should be applied in geoarchaeological assessments (Barham and Macphail 1995; Barham 2008; Butzer 1982; Czastka 2018; French 2003; Goldberg and Macphail 2006; 2018; Historic England 2018; 2020; Stein 2001). The conceptual geoarchaeological model developed by Karkanas and Goldberg provides one of the best, and certainly the most accessible summary (2020: 2):

- *'A site is a three-dimensional arrangement of artefact-bearing deposits, therefore the fundamental unit of a site is the deposit, not the artefact or the pattern of the artefacts.'*
- *The deposits have accumulated by natural or anthropogenic processes or a combination of these.*
- *The fabrics of the sediment are indicative of the different processes involved in their formation.*
- *Traditional artefacts (pottery, flints, etc.) are fabric elements within archaeological deposits.*
- *Architectural features (e.g. walls, mosaics, etc.) may have their own typology and internal stratigraphy but the relationship between construction phases and the surrounding artefacts is mediated by the enclosing deposits.*
- *Natural deposits in a site may have a cultural meaning (e.g. sediments trapped within aqueducts).*
- *All elements that form a deposit should be treated as having equal importance with the traditional items of the archaeological record (architecture, pottery, lithics, objects, etc.) in the study of a site.*
- *Time resolution is essentially determined in the field by how finely we can recognize the vertical and horizontal extent of individual stratigraphic units, which are the proxies for activities and processes. Similarly, such units should be recognized and recorded only during excavation and not after...'*

Although some of the examples given for features are not necessarily relevant in an Australian Aboriginal archaeological context such as mosaics, there are plenty of examples such as middens, hearths or earth mounds that can be substituted, and flints can include the known raw materials used such as silcrete, quartz or tuff. In terms of cultural meaning, one need only think about archaeological features that demarcate ceremonial Bora Grounds or stone alignments as comparative features. This conceptual model provides the *de facto raison d'être* for geoarchaeological frameworks in archaeological programs.

1.5 Assumptions and Limitations

The assessment of deposits resident across the study area has been undertaken using existing sources such as available geomorphological (Thom and Ollier 2019, geoarchaeological (Czastka 2019; Steele and Czastka 2020), geological (Gale et al 2018; Troedson 2015; Roy and Boyd 1996), geotechnical studies (Douglas Partners 2019; 2020), and archaeological reports (Steele and Czastka 2020). This background data provided a chronological, palaeoenvironmental and archaeological framework for understanding the geomorphological character of the landscape of the study area. Thus, this archive provided the preliminary stratigraphic framework that forms the basis of the depositional history presented, but it is important to note that these are a series of working models (preliminary hypotheses), rather than a factual representation of stratigraphic events. This preliminary scientific assessment of *sensitivity* requires fieldwork and laboratory analysis of samples to translate into *significance* as a value. Therefore, the caveat for this geoarchaeological desktop assessment is that subsequent work is required in order to confirm, reconsider, or refine the stratigraphic framework (hypothesis) presented in this report using scientific techniques to quantify these attributes. Undertaking laboratory analysis using at least two methods in order to cross reference the results –with chronological controls – is necessary to finalise the scientific assessment of significance and distinguish PAD and non-PAD.

1.6 Authorship

The geoarchaeological report was written by Jakub Czastka (Principle Geoarchaeologist). The cross section, site formation model and GIS plans were produced by Eric Claxton (assistant geoarchaeologist). The technical review was undertaken by Bryce Sherborne-Higgins (geomorphologist). Any mistakes in the report are however the responsibility of the author.

1.7 Acknowledgements

The author would like to thank Jesse Lockhart-Krause for facilitating this study and Dominic Steele (Dominic Steele Consulting Archaeology) for letting me take carriage of the geoarchaeological aspect of this project.

2.0 Environmental Review

2.1 Introduction

The following section includes a review of existing environmental background data such as geological mapping and previous geomorphological, soil, geoarchaeological and archaeological investigations. This chapter is aimed at providing a contextual framework in which to understand the study area within its landscape context and highlight the considerable changes that the landscape has seen as climates ebbed and flowed between the cold dry climates of the ice ages to the warmer and wetter conditions of interglacial cycles. It builds on the available evidence and presents a preliminary interpretation of the available geotechnical data for the study area. A simple geoarchaeological site formation model is devised to illustrate to the reader how the study area's geomorphological character has evolved as sea levels and climates have changed.

Consideration of the natural environment and its history of climatic and physical change is a key component to understanding past Aboriginal settlement patterns, people's use of resources and tracing how their economic and subsistence strategies may have evolved and adapted through time. The sedimentary archive is made up of soils and sediments, human-made deposits and features that form part of the archaeological record. They are however increasingly subject to impacts that remove these deposits down to bedrock. A basic tenet of archaeological enquiry is to understand the sedimentary archive through stratigraphic methods and techniques based largely on the earth sciences (geoarchaeology), with environmental data on past climates, sea levels and hydrology (palaeoenvironmental or climate studies) contributing to our knowledge of how people responded and adapted to changing conditions over the last 40,000 years.

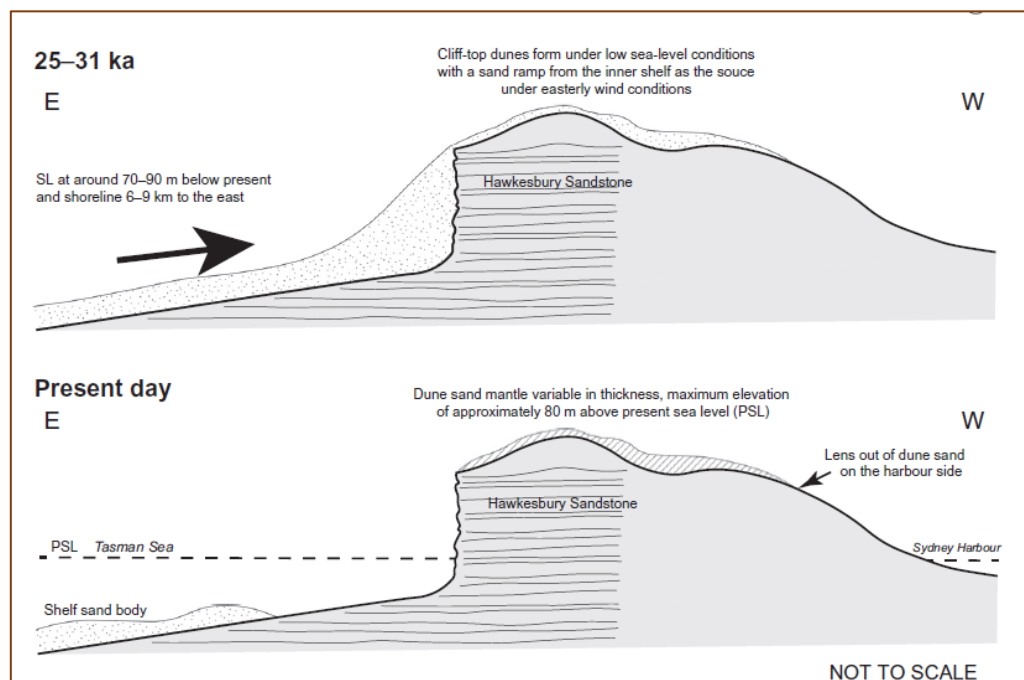


Figure 2.1: Schematic model of cliff-top deposition in the Vaucluse area. This model contrasts present-day conditions with hypothesised cliff-top dune formation during the period 31–24 thousand years ago (Source: Figure 4: Thom and Oliver 2019).

A simple illustration of the importance of these studies is the observation that during the LGM, Bondi Beach was situated some 10 (to the southeast) or 12 (to the east) kilometres inland from the coastline and formed part of an escarpment mantled in places by sand dunes (Thom and Oliver 2019: Figure 2.1). This reflects a vastly different landscape setting and environmental character to the modern Bondi Beach. It also highlights the importance of considering the palaeoenvironmental and climatic context when trying to interpret the archaeological record of the study area.

2.2 Geology

The underlying bedrock geology of Bondi Beach, and the Eastern suburbs generally, is composed of Hawkesbury Sandstone dating to the Triassic ~251-201 million years ago (Herbert 1983). The sandstone is exposed across wide areas, with the remaining deposits mapped as sediments mantling the bedrock: these sediments are the geological deposits of interest to archaeologists (Figure 2.4).

The deposits that mantle this bedrock are all Quaternary in age (2.58 million years ago to the present), with the majority almost certainly dating to the Upper Pleistocene (126,000-11,700 years ago) and Holocene (11,700 years ago to c.1800 AD) epochs and stages. These deposits and their stratigraphic relationships form part of one landform system – a coastal barrier - and this provides a framework to unravel the processes that have created the sediment mantle across the sandstone bedrock at Bondi Beach and surrounds (Figure 2.3). This landform system has differential potential for Aboriginal archaeological deposits depending on three factors:

1. Geomorphic setting (e.g. dune, lagoon, ridgeline etc).
2. The nature of the deposit (e.g. transported or residual topsoil, subsoil, colluvial or aeolian sediment etc).
3. The relative position or superposition of all deposits within a stratigraphic matrix (e.g. surface and subsurface extent of individual deposits and their physical relationships).

These factors influence the potential context of archaeological finds and predicts whether archaeological objects, features or deposits are found on ground surfaces, reworked or buried within topsoils, or buried in stratified archaeological and/or natural sediments. Conversely, it identifies deposits with no archaeological scientific significance such as fills resulting from earthworks such as landscaping or construction etc.

There are four main types of geological formations on or around the study area (Troedson 2015; Figure 2.4):

- Qhbb: Holocene sandy beach: marine sand, shell, gravel.
- Qhbd: Holocene dune: marine sand.
- Qhbdr: Holocene bedrock mantling dune: marine sand.
- Qpbdr (only illustrated in Figure 2.3): Pleistocene bedrock mantling dune: marine sand, indurated sand.

All these geological formations include a major component of marine sand which means the landform and stratigraphic position are critical in understanding their chronology and as such, their potential to preserve surface or deeply buried archaeological deposits (PAD). The existing science on these geological formations identifies a deep and complex sedimentary archive, with the potential for archaeological objects (e.g. stone

artefacts) or archaeological features (e.g. hearths, post holes) to be located at any depth within the Holocene formation and down to an unknown depth into the Late Pleistocene formation (Czastka 2019, Steele and Czastka 2020).

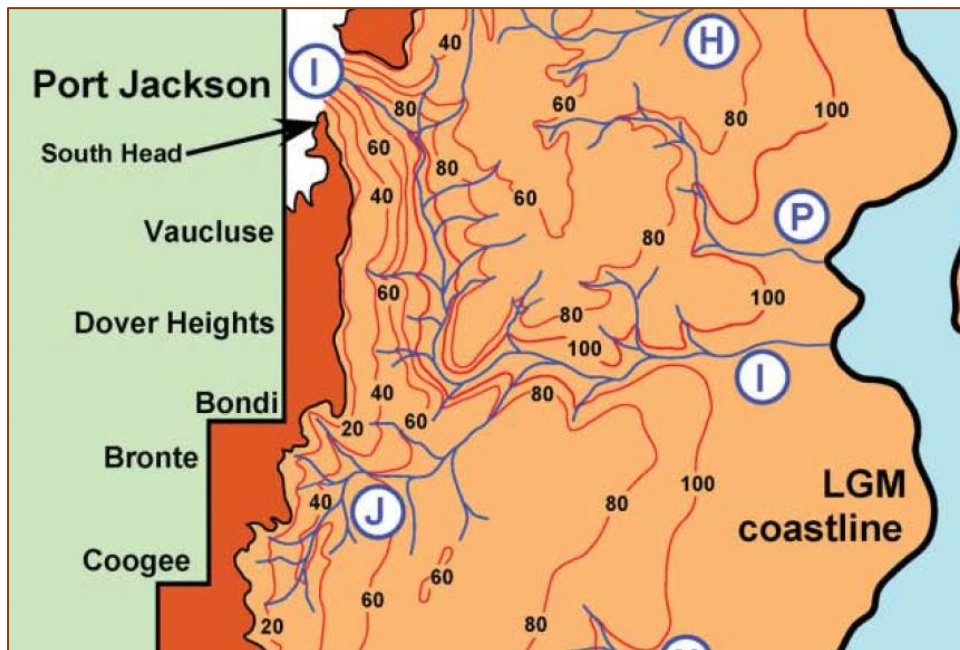


Figure 2.2: Detail illustrating the Bondi paleo-watercourse (J) draining into the Parramatta River paleo-watercourse (I) before draining into the ocean (Source: Figure 3: Albani et al 2015).

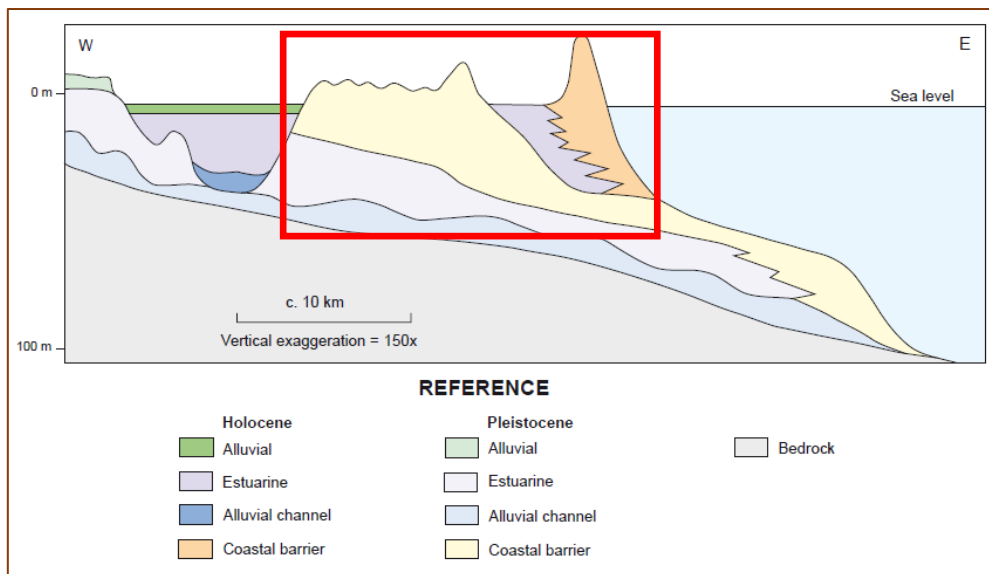


Figure 2.3: Generalised morpho-stratigraphic relationships between Quaternary deposits in NSW. The area within the red box reflects the pre-1788 landscape attributes of the study area (Source: Troedson et al 2008: Figure 9).

The study area itself is located on the Holocene dune formation and close to the boundary of the Holocene sandy beach formation (Figure 2.4). These deposits have been steadily building over the Late Pleistocene and Holocene and mantle the area from Bondi Beach to Rose Bay. In addition to the terrestrial Pleistocene and Holocene sand dune formations of the Eastern suburbs and Botany Bay areas, vast deposits of offshore sand

are located on the continental shelf, forming the source material for the dune systems (Roy and Boyd 1996; Whitehouse 2007). Previous studies of the Quaternary deposits of the Sydney 1:100 000 Geological Sheet recorded the deep nature of the stratigraphic sequence between Rose Bay and Bondi Beach (Roy 1983). A geological cross section described some 60 m of sands mantling the sandstone bedrock at Rose Bay, dropping to some 20 m of sand at North Bondi where the bedrock rises, before again deepening to some 40 m at Bondi Beach before bedrock is reached (ibid). This configuration of the subsurface bedrock topography reflects a watershed between two creek systems that comprise a northwest facing catchment with a tributary of the paleo-watercourse of the Parramatta River within Port Jackson centred on Rose Bay, and a northeast facing catchment with a Bondi paleo-watercourse – also a tributary of the Proto-Parramatta River - draining across the exposed continental shelf during times of lower sea level (Figure 2.2). Port Jackson is a drowned river valley with paleo-drainage that drained through North and South Heads to a palaeo-channel running east towards the coast about 10-12 kms offshore (Figure 2.5; Roy 1983; Roy and Boyd 1996; Albani et al 2015; Thom and Oliver 2019; Och et al 2017). Based on the seemingly continuous nature of the sand body between the ocean at Bondi and the harbour at Rose Bay, it was previously thought this geological feature represented an old landscape ‘outlet’ to the harbour (Dowd 1959:47). However, more recent geological analysis shows such a channel never existed and the sand dunes are divided by a sandstone ridge located between Waverley and Dover Heights and form essentially the same catchments as today (Roy 1983:76).

The drainage of Bondi Beach was initiated around modern-day North Bondi along a sandy ridge orientated north-east to southwest and flowed into the paleo-watercourse of the lower reaches of the Proto-Parramatta River, across what is today the submerged continental shelf (Figure 2.2). In terms of the potential stratigraphic profile across the Bondi Surf Club study area based on previous work, it is highly likely the Holocene bedrock mantling dune overlies earlier Pleistocene marine sands reworked as an earlier dune system (coastal barrier), alluvial plain or estuarine deposits from the Last Interglacial. There is about 40 metres of sediment before bedrock is reached beneath the study area (Roy 1983), and this sediment profile may potentially reflect different sedimentary environments (Figure 2.3).

In summary, the stratigraphic architecture of the coastal barrier system in which the study area is located suggests a deep, complex sedimentary archive that interdigitates between different geological formations reflecting different geomorphic processes (Figures 2.3-2.4). There is therefore the potential for stratigraphic complexity with physical relationships horizontally and vertically between deposits and PAD in both shallow contexts directly beneath fills, as well as within deep subsurface contexts. As indicated previously, Pleistocene deposits are likely to be mantled by the transgressive dune systems of the Holocene. The following sections on hydrology, sea levels and geomorphology explore the landforms of today’s coastline and those of the now submerged inner continental shelf. The continental shelf was once part of a larger coastal plain and we propose a generic model for the Quaternary stratigraphy of the study area based on the existing data (Albani et al 2015; Roy 1983; Roy and Boyd 1996; Thom and Oliver 2019; Troedson et al 2008; Troedson 2015; Steele and Czastka 2020). In doing so, we place the study area into its landscape context which allows us to investigate site formation processes and post-depositional changes to potential archaeological deposits of the study area.

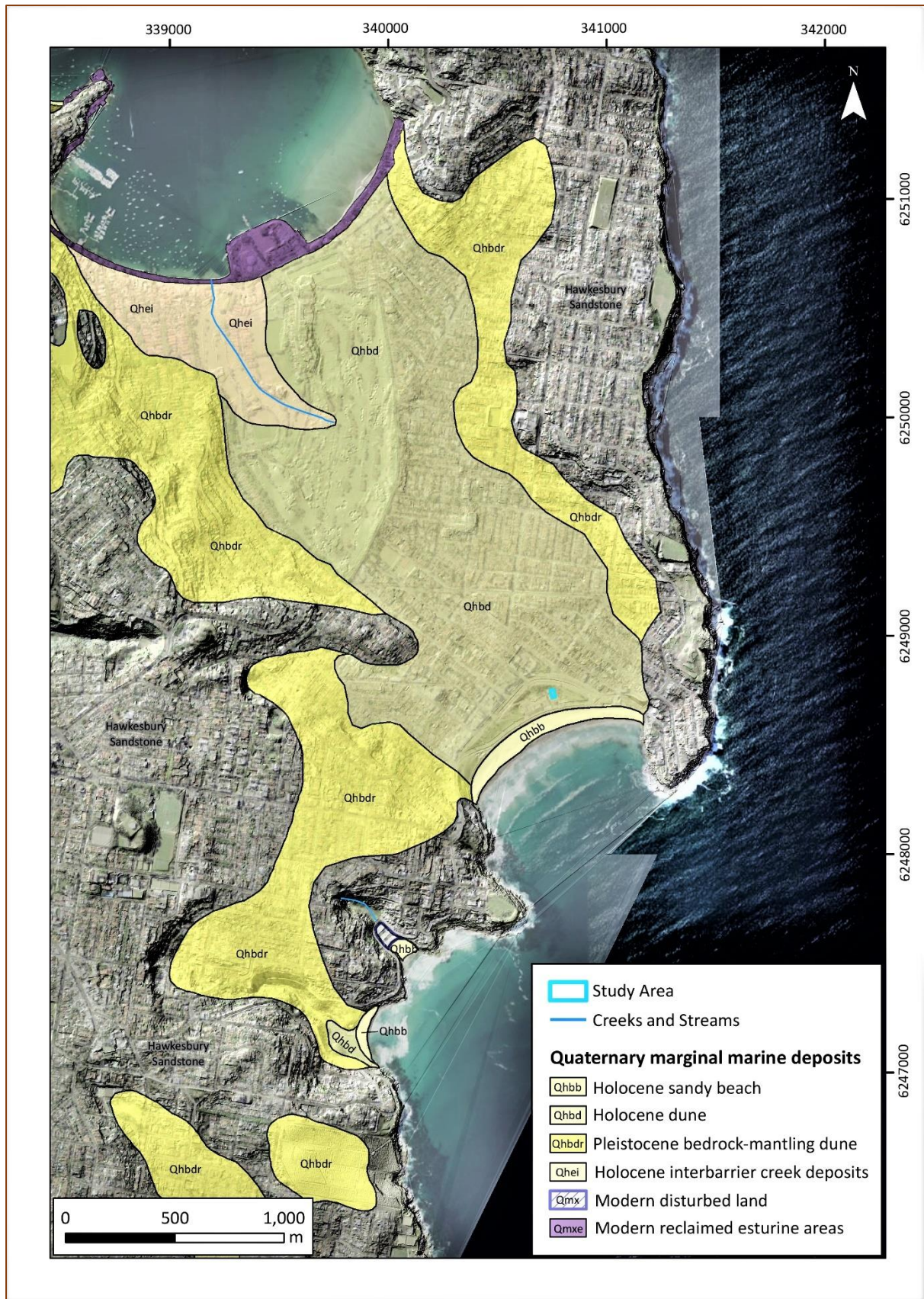


Figure 2.4. Quaternary geology of the study area and surrounds (Source: Troedson 2015).

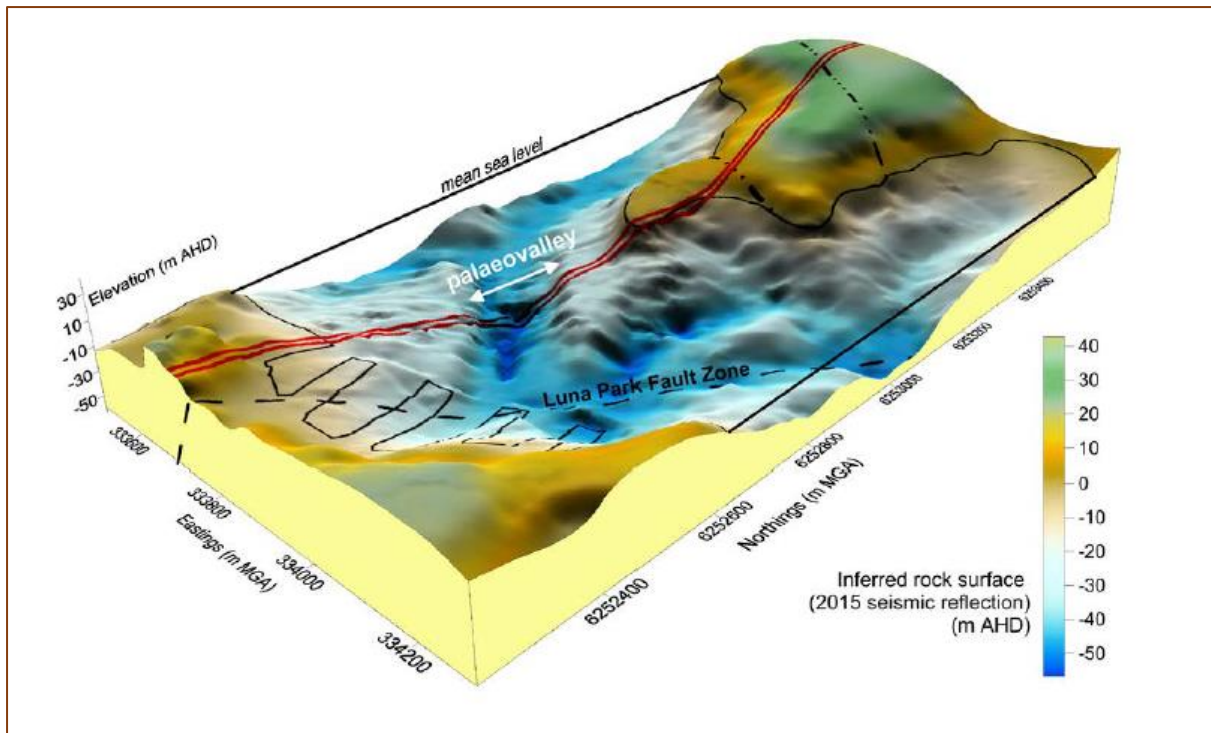


Figure 2.5. The drowned river valley (palaeo-valley) of the Proto-Parramatta River in Port Jackson: the red line is Sydney Harbour crossing (Source: Och et al 2017).

2.3 Hydrology and Sea Level Changes

Hydrology is intricately linked to climate because there are generally long-term trends (e.g. colder, drier climates with lower sea levels versus wetter, humid climates with higher sea levels such as today) interacting with short term trends (e.g. two-to-seven-year average of the El Nino-Southern Oscillation (ENSO) cycle). The topography and terrain of Sydney has been shaped over a long period of time, but the most relevant processes encompass a series of the last Interglacial, Glacial and Interstadial climatic regimes, with the more recent post-1788 (Anthropocene) impacts being the most destructive and widespread. Over these geological timeframes sea levels have generally been lower with a larger exposed continental shelf (Albani et al 2015). Drainage patterns have changed with the rise and fall of sea levels, but the overall trend over the last 15,000 years or so indicates rising sea levels. The more recent historical impacts to the landscape have however created an almost unrecognisable drainage network, with the destruction of lagoons, swampy meadows (also known colloquially as ‘chain-of-ponds’), the entrenchment of creeks and emplacement of water storage or drainage systems across the landscape, such as dams, stormwater and retaining basins (Allen 2013; Butzer and Helgren 2005; Cook 2019; Lawrence and Davies 2020; Eyles 1977; Mactaggart et al 2007).

In this section we review how sea level changes and climatically controlled hydrological regimes have shaped the Sydney landscape, and why it has implications for Aboriginal settlement patterns and the detectability of the archaeological resource. What we will discuss briefly is the changing nature and availability of water in the Sydney and Eastern Suburbs area concentrating on the last 40,000 years, as this lies within the potential timeframe of Aboriginal occupation in the Sydney Basin. This ancient Aboriginal relationship with Country goes back at least 65,000 years for the Continent (Clarkson et al 2015; Clarkson et al 2017), some 50-46,000 years

for NSW (Bowler et al 2003) and at least 40,000 years for the Cumberland Plain (Nanson et al 1987; Stockton and Nanson 2004; GML 2019). The availability of water is one of the key factors that has a direct influence on the presence, nature and longevity of Aboriginal settlement patterns. The recent floods of March 2021 once again highlighted the fact that, regardless of what we do in terms of flood mitigation, certain areas will be inundated when extreme rainfall events such as a 1:100-year flood occurs, particularly in the middle and lower reaches of river systems. This is an important observation because there have been wetter climatic regimes over many of the previous Quaternary stages. This means that large scale floods would have been more common and potentially, more extreme in the past.

The key Marine Isotope Stages (MIS) that are important in terms of hydrology and sea levels include (Murray - Wallace and Woodroffe 2014; Figures 2.6-2.7):

- The Last Interglacial (MIS5e ~126-116,000 years ago);
- The Last Glacial cycle (MIS5-2 ~115,000 – 11,700 years ago), which included:
 - Two short Interstadials of the Last Glacial cycle (MIS5c and a: ~105,000 and ~82,000 years ago respectively);
 - A longer Interstadial of the Last Glacial cycle (MIS3: ~64,000-32,000 years ago); and
 - The Last Glacial Maximum [LGM] (MIS2 ~27-17,000 years ago); and
- The current Interglacial cycle (MIS1: Holocene 11,700 years ago until c.1800 and henceforth the Anthropocene).

The processes acting between MIS5e until the peak of MIS2 generally represented a gradual fall in sea levels and the extension of the coastal plain. At the same time, increased hydrological activity has been noted for alluvial chronologies identified across various locations in NSW. Three periods of increased rainfall have been identified on the alluvial floodplain of the Hawkesbury-Nepean River: these date to 110-70 Ka, from 55-34 Ka and then again c.20-12 Ka (Barham 2008: 23). As sea levels fell, drainage networks adjusted accordingly because of the increasing distance to the coastline. These adjustments included steeper channel morphology – i.e. channels were incised/entrenched – and longer, deeper river valleys. The inferred increase in stream power noted for the three phases above also left behind stratigraphic markers in the form of alluvial terrace sequences and played a part in stream and floodplain dynamics (Figure 2.5). It is important to remember that throughout the period MIS5e to MIS2, the study area was further removed from coastal influences than today (Figure 2.2). Importantly, there were no estuarine, intertidal or marine influences throughout the Last Glacial cycle on or near the study area (Figure 2.6). These were only reactivated in full around the time that sea levels reached current levels some 6,000 years ago (Figures 2.7-2.8).

The period post-dating MIS2 produced a series of gradual rises in sea level interspersed with more rapid but short-lived episodes. This resulted in the eventual loss by around 6,000 years ago of the coastal plain of the low-lying continental shelf, and the drowning of river valleys such as those of the Proto-Parramatta River and palaeo-water courses like the palaeo-Bondi Creek (Attenbrow 2002; Murray -Wallace and Woodroffe 2014; Williams et al 2012; Steele and Czastka 2020). This relatively rapid drowning of coastal plains and river valleys in the Terminal Pleistocene and Early Holocene meant that estuaries and wetlands were unable to become

established (Figure 2.8). This changed dramatically after current sea levels were reached around 6,000 years ago (known as 'stillstand'). Even though there is evidence that sea levels rose some +1-2m in the period after this stillstand (ibid), the coastline did not change anywhere near as dramatically as it had done in the preceding phase of rapid sea level rise. There is also evidence that post-glacial sea level rises sent 'saltwater wedges' up rivers such as the Hawkesbury, where saline algae (Dinoflagellates) have been identified as far upstream as the Colo River, NSW during the Terminal Pleistocene-Early Holocene (*pers.com. Dr. Mike Macphail. 17 June 2020*). Significantly, stillstand meant that for the first time in thousands of years, estuaries, lagoons and wetlands could become established along a more constant shoreline.

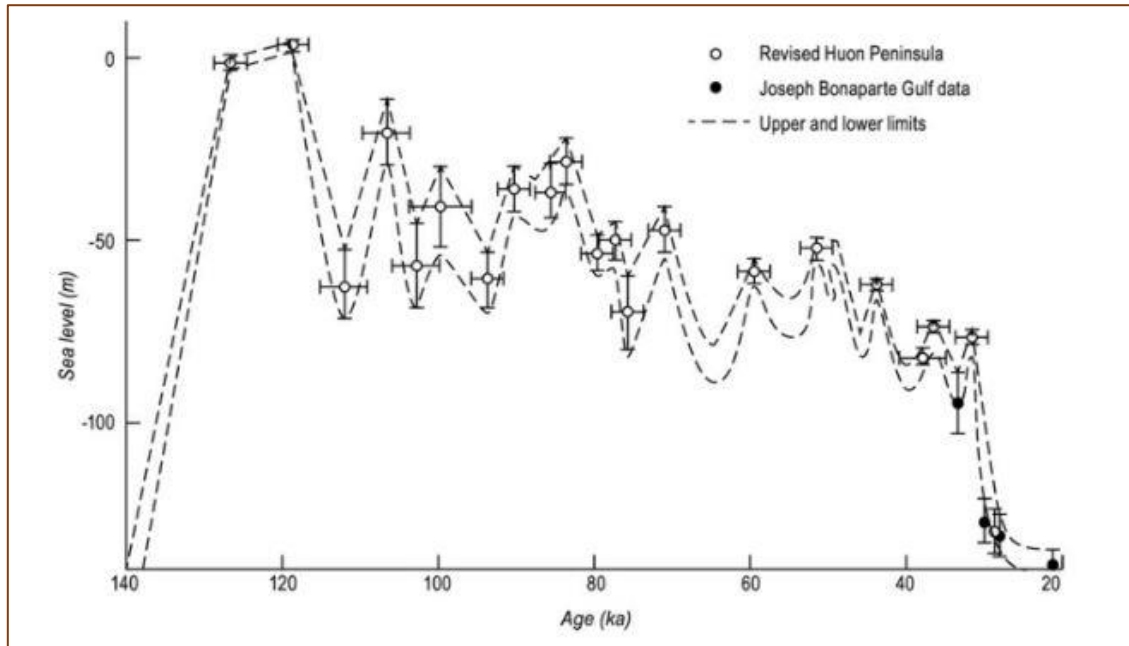


Figure 2.6. Age-depth plot of Late Pleistocene sea-level indicators and inferred sea-level changes from the Houn Peninsula, PNG and the Joseph Bonaparte Gulf, NW Australia (Source: Lambeck and Chappell 2001 in Murray -Wallace and Woodroffe 2014 Figure 6.80: 281).

The changes due to rising sea levels have meant that the relative positions of ecological zones such as estuaries, riparian zones and wetlands were constantly changing for most of the last 65,000 years. This would have had knock-on effects for the availability and distribution of resources. As Attenbrow noted at a regional level (2002: 38-39), the loss of the inner continental shelf inundated some 11,000 sq km of terrestrial resources, excluding the palaeo-valleys, but at the same time a considerable length of estuarine shoreline with protein rich resources was created. Attenbrow's (ibid) estimated that for Port Jackson - an area of 45-50 sq km - some 240 to 250 km of estuarine shoreline was established. This inundation of the inner continental shelf and the drowning of the deeper river valleys also means that much of the Pleistocene archaeological landscape is not readily accessible to archaeologists. This shift in the position and relative carrying capacity of resources in the landscape, the shrinking size of the coastal plain, and the continuing rise of sea levels during the Early to Mid-Holocene, indicates that the nature and position of Aboriginal settlement patterns must have adapted dramatically in the run up to the stabilisation of sea levels around 6,000 years ago.

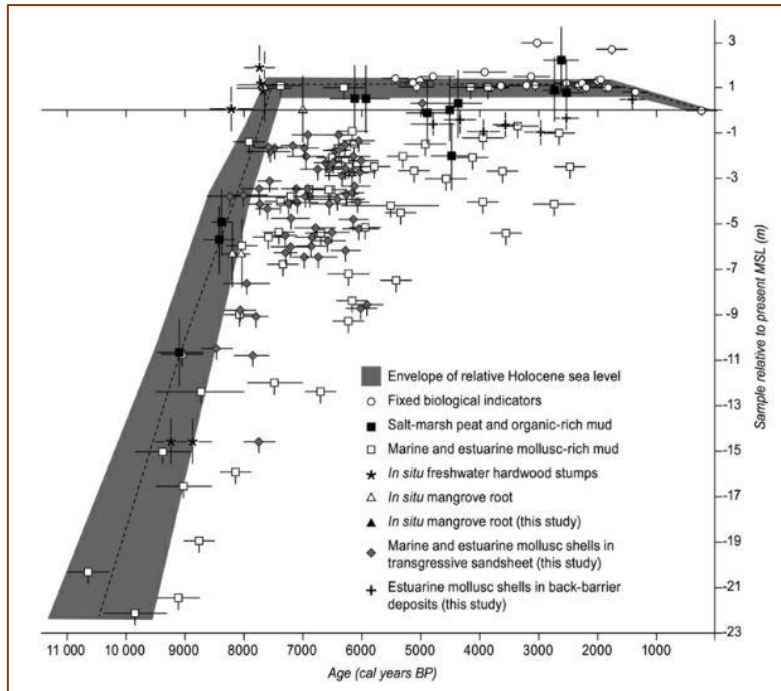


Figure 2.7. Sea-level compilation and revised envelope for the Holocene of south eastern Australia (Source: Sloss et al 2007 in Murray -Wallace and Woodroffe 2014 Figure 7.6: 335.

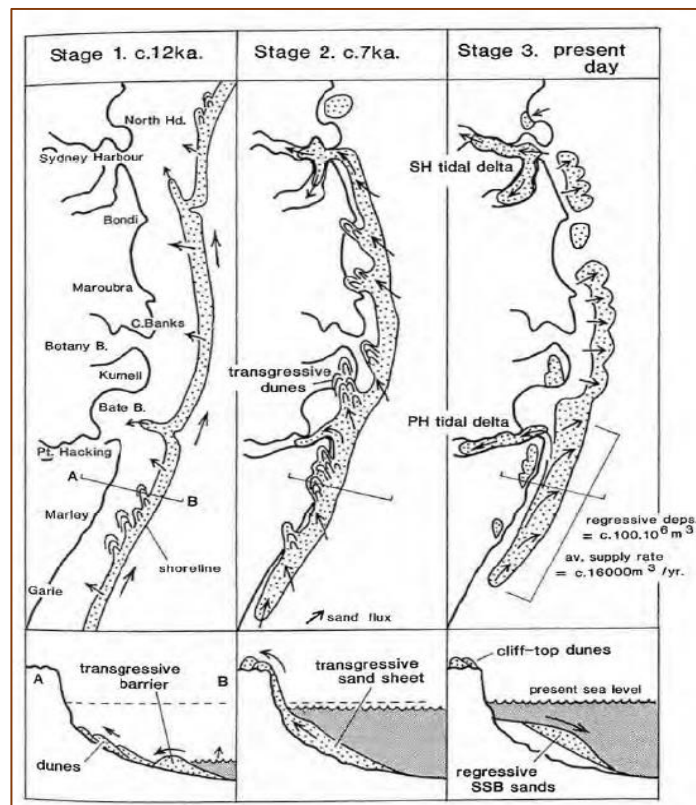
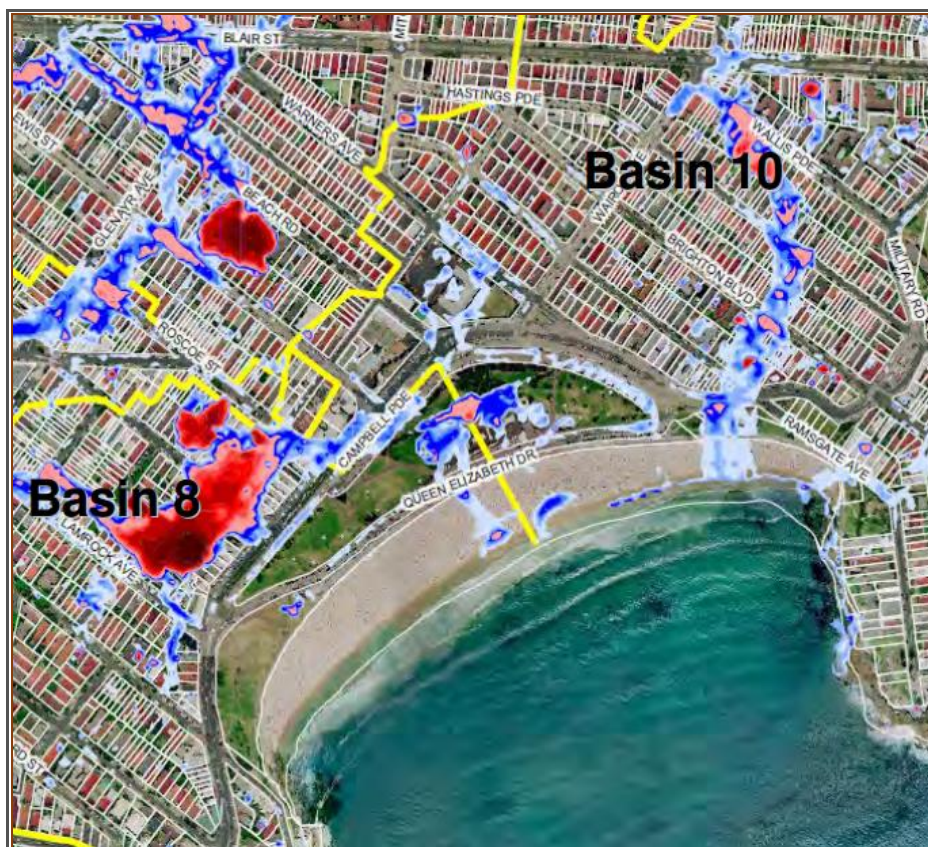


Figure 2.8. Model illustrating three stages in development of the Sydney Sand Body from when sea level was rising rapidly (Stage 1), the end of the marine transgression (Stage 2) and after a 6,500 year period of stable sea level (Stage 3) (Source: Roy and Boyd 1996: Figure 0.10).

Reconstructing the Late Holocene and early Anthropocene hydrology of the study area provides us with a glimpse into the availability of fresh water in the vicinity of the study area, a prerequisite for human settlement. The inter swale areas behind the fore-dunes of Bondi Beach included a series of freshwater lagoons fed by at least two (and possibly more) creeks that flowed down eastwards from the sandstone ridge along which Old South Head Road was aligned (Figure 2.9). Some of the lagoons appear to have been small and seasonal, enlarging and disappearing quickly depending on rainfall, however others were large and permanent (compare Figures 2.12 and 2.14). A few of the lagoons were situated some distance inland, one formerly present in approximately the location of present-day Hall Street and Jacques Avenue, eventually running into the ocean at the southern end of Bondi Beach. The fate of these lagoons is discussed shortly. While the historical location of some of the larger lagoons are known or can be reasonably inferred from historical maps of plans of varying purpose and hence accuracy, some were small and most likely seasonal/ephemeral in nature and therefore their locations and extent would have varied over time dependant on prevailing climatic conditions (Steele and Czastka 2020).



2.9. Natural detention basins behind Bondi Beach: these are likely to reflect the position of now subsurface palaeodrainage patterns at Bondi Beach (Source: Civic Design 2007 in Steele and Czastka 2020).

2.4 *Late Pleistocene and Holocene Geomorphology*

The topography and terrain of Bondi Beach and its environs is a product of a coastal barrier system that formed over a period encompassing a series of Interglacial, Glacial, Stadial and Interstadial climatic regimes. Importantly, the processes acting over the Last Glacial cycle and during the peak of the LGM, generally reflected a gradual fall in sea level and the extension of the coastal plain, with vast deposits of sand blanketing the now

submerged continental shelf. The continental shelf would have resembled the (unmodified) Botany Bay dune landscape of today, with palaeo-waterway tributaries like Rose Bay's Creek draining into the Proto-Parramatta River (Figure 2.5). The Proto-Parramatta River exited Port Jackson between North and South Heads and drained east across a dune field dotted with freshwater lagoons and tributaries like the Bondi palaeo-waterway (Figure 2.2). This landscape represented an alluvial plain system located within a coastal barrier system that graded into an estuarine plain, and finally a subaqueous geomorphological zone (Figures 2.2 and 2.3). A lower sea level and extensive coastal plain placing Bondi away from the coast would have meant wind and potentially alluvial and fluvial processes were largely responsible for the creation of the geomorphology. Conversely, the shrinking of the coastal plain because of rising sea levels initiated in the post-LGM would have decreased the supply of marine sand, subsequently creating the modern configuration of the beach at the time current levels (stillstand) was reached 6,000 years ago (Figure 2.4). Bondi Beach therefore forms part of a drowned valley type coastline with a continental shelf sand body known as the Sydney Shelf Sand Body (Roy and Boyd 1996).

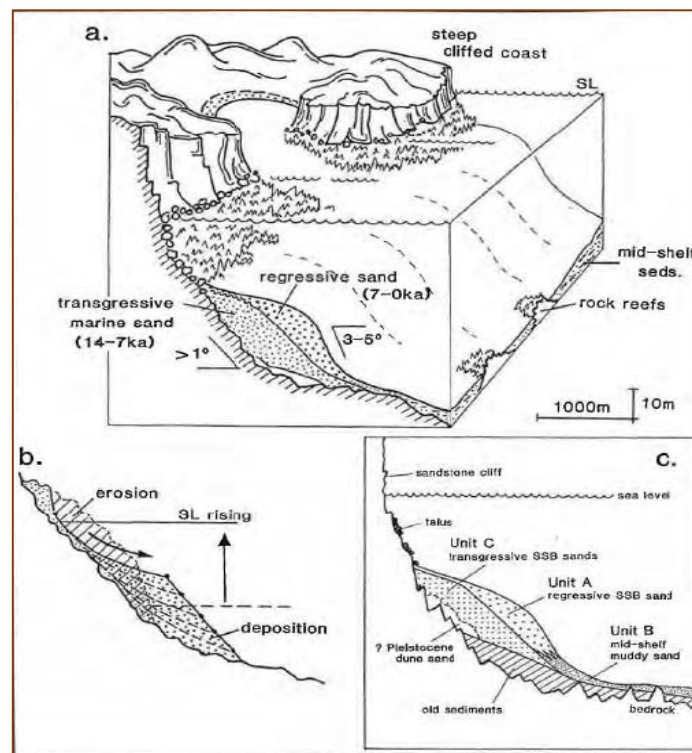


Figure 2.10. Model illustrating continental shelf sand bodies (Source: Figure 0.8; Roy and Boyd 1996: 19-20).

- a. Shelf sand bodies occur along steep and deep sections of coast in southeast Australia and comprise transgressive and regressive units deposited subaqueously during the postglacial marine transgression and the following stillstand.
- b. At all stages of their formation, the direction of net sand movement was seaward.
- c. Idealised stratigraphic cross-section through the SSB showing relationships between the three main sediment units.

The post-LGM represented a change in conditions with a gradual – interspersed with rapid – rises in sea levels (Albani et al 2015; Murray -Wallace and Woodroffe 2014; Roy and Boyd 1996; Williams et al 2012). The general rising of sea levels would have favoured different geomorphological environments and associated landforms,

as is reflected in the four Quaternary geological formations mapped in and around the study area: Holocene sandy beach, Holocene dune, Holocene bedrock mantling dune and Pleistocene bedrock mantling dune. It also included ancillary landforms associated with coastal barrier and estuarine plain landform patterns like mangrove swamps and mudflats. These have now been translocated to different landscape positions than those of the past (Troedson et al 2008; Roy 1983; Roy and Boyd 1996;). This is a function of how climate systems interact with geomorphological processes depending on how close - or distant - the coastline is at any given time.

This interpretation of the pre-1788 Bondi Beach landscape is consistent with the models of Roy (1983), Roy and Boyd (1996), Albani et al (2015) and Thom and Oliver (2019). It highlights the movement of marine sands, where the nature of relict verses active geomorphic processes depends on sea level, climate (hydrology, wind and temperature in particular), the relative size of the coastal plain and the availability of sediments (Figure 2.10).

2.5 Historic transformations of the Bondi landscape

The following two sections (2.5 and 2.6) are sourced from Steele and Czastka (2020).

The images below provide a historical overview of the size and scale of sand hills that were originally at Bondi, with lagoons and streams behind them in swales and occupying low topography, and how they were progressively drained, filled and built over (Figures 2.11-2.14). It is likely that the lagoons at Bondi began to disappear from the early 1880s. A report of work in progress on the main Bondi sewer in 1883 (*Illawarra Mercury*, **4 September 1883**) made references to the need for a second vertical shaft to be sunk into the rock about 10 chains (200m) from the initial tunnel and cliff outfall point 'with a view of getting under the sand' to facilitate the execution of the work. About 760m had to be tunnelled through the sandy length of the lagoon and would be finished when the tunnel through sand and under Old South Head Road was finished. At least two large lagoons in North Bondi were drained around this time when a trench was built through to Rose Bay, and later other swamps, ponds and lagoons were drained for roads and land subdivision for housing.

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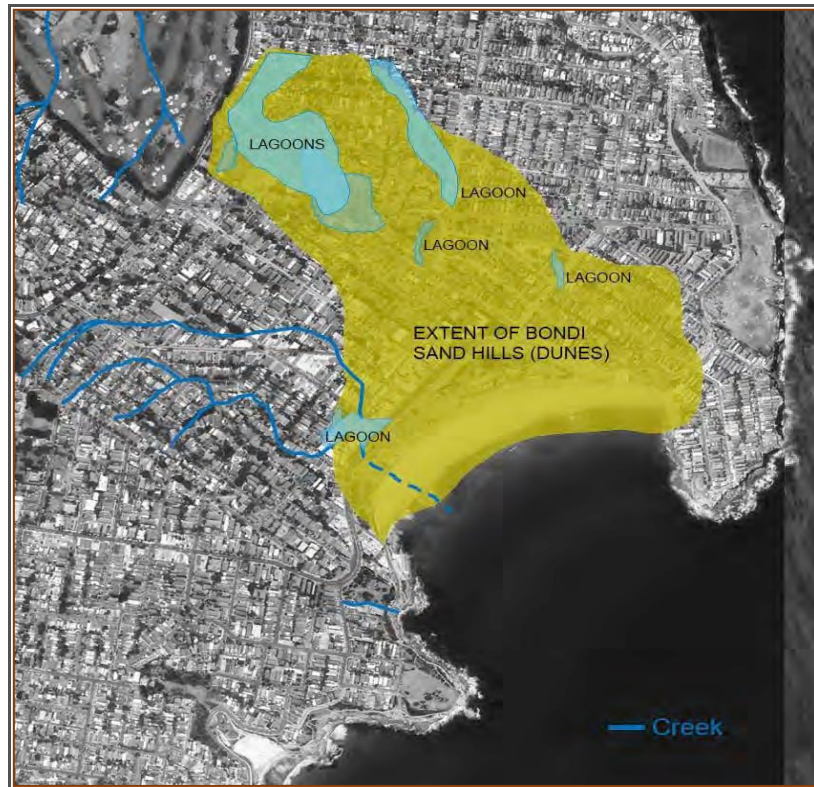


Figure 2.11. Lagoons and sand dunes and drainage at Bondi (Source: Steele and Czastka 2020).

'In my younger days Bondi was plentifully supplied with water in the form of lagoons which extended from the north of the sand dunes to well over to the Old South Head Road. I remember the largest of them, near Barracluff Park....They dried up somewhat in the summer, but in the winter, and after heavy rain, the country would be covered – the lagoons linking up with one another and forming one large sheet of water. I have rowed a canvas dinghy...over the present Murrivier Road and adjacent streets. We struck a submerged stump one day...it was retrieved when the lagoon dried up. Another lagoon was situated to the left of the sewer line, one edge of the water lapping the edge of the ever-encroaching sand hill, the other shore lost among the trunks of the big ti-trees and undergrowth...This lagoon was the first to dry up and disappear, the sewer track draining it and the sand gradually smothering the site.' ('Plugshell' 1924a).

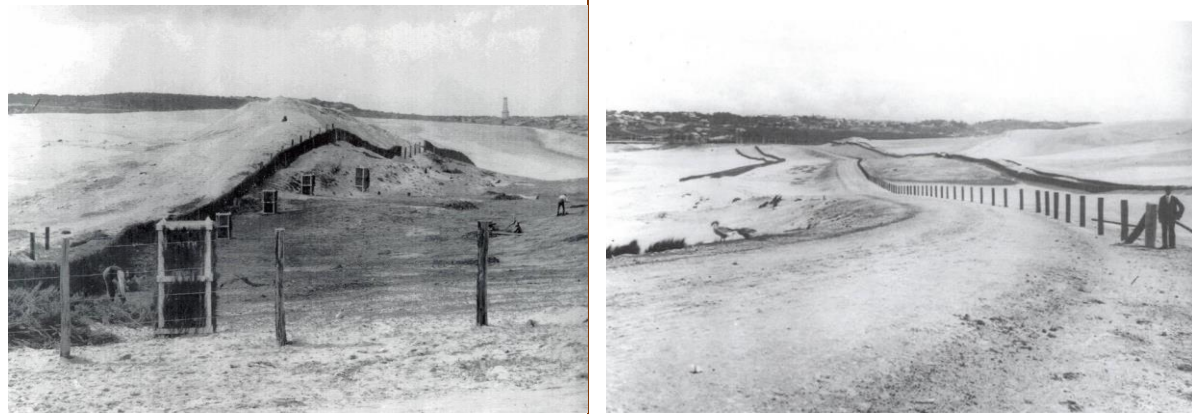
The image to the left shows Bondi Park in c.1885 showing (indicatively) a large lagoon set back from the beach at the eastern end of Hall Street and drainage flowing south and east from higher elevations. The image to the right shows the dune fields at Bondi in 1875 - a partly vegetated parabolic dune at the north end of the bay – that originally had large and small freshwater lagoons trapped in dune swales (Waverley Image Library).



Figure 2.12. Extensive dune fields and drainage networks with lagoons dominated the back of the beach landscape in the 1870s and some lagoons persisted into the 1920s. The largest of the last remaining sand dunes had been lowered and flattened by the late 1920s.

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Mobile sand dunes in the 1900s in the area of future Campbell Parade (left). The wavering lines were brush fences used to contain drifting sand and 'shape' the sand hills. Bondi was the first area used in NSW for experiments in sand stabilisation using brush fences and introduced plants. Some of this sand was removed by mining but most was 'flattened' behind the beach for subdivision and housing. The image to the right is undated but was probably also recorded in the 1900s with brush fencing and possibly plantings used to contain drifting sand (Waverley Image Library).



Bondi Beach sand dunes – c.1900 – (windswept) Ti trees and scrub (left) and livestock grazing contributed to the destabilise the vegetation and extensive sand drifts are recorded between Bondi Beach and Bellevue Hill (2-3 km inland) by the 1920s (Waverley Image Library).

Figure 2.13 Dune fields at Bondi in the early 1900s.

The dune fields that originally extended from the back of the beach to Rose Bay originally had large and small freshwater lagoons trapped in dune swales. The image to the top left is a 1890s view of a large lagoon that was formerly at the 'back of the beach' at Bondi (left) and undated view of another lagoon at Bondi is to the right (Waverley Image Library). These photographs may record a former lagoon that was situated in approximately the location of present-day Hall Street & Jacques Avenue for example that originally drained out at the southern end of the beach. The bottom images show how these historic lagoons were drained - undated - swamp drainage in progress for the construction of the Bondi Ocean Outfall Sewer (Water NSW) and the image to the bottom right shows this section of the Bondi Ocean Outfall Sewer was oviform and brick lined (Water NSW).



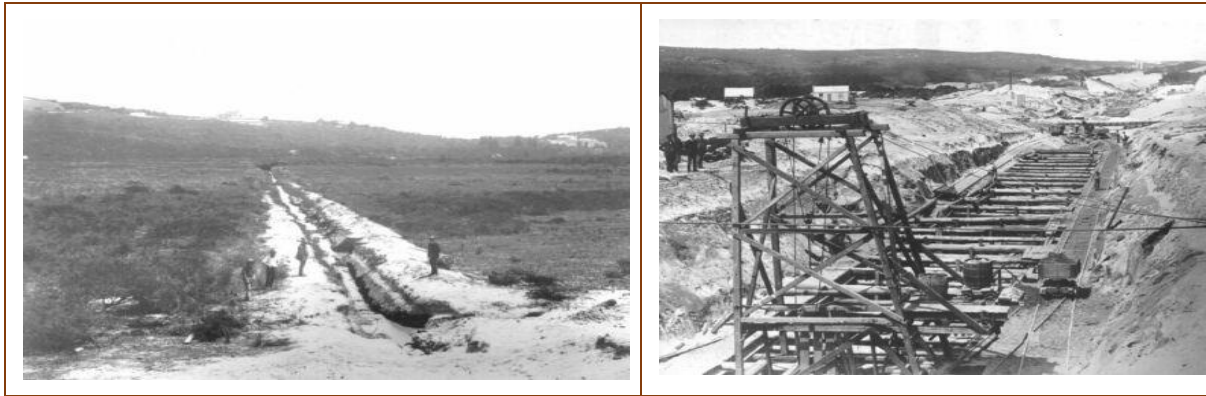


Figure 2.14. Lagoon and swamp draining.

2.6 Geotechnical information: Bondi Pavilion

Geotechnical information (Douglas Partners 2015) confirms that Bondi Pavilion immediately west of the study area is underlain by medium to fine grained marine sand with podosols (also known as podzols) that form part of a transgressive dune system deposited by aeolian processes. The area to the south of the site is underlain by modern beach sands. The groundwater table is 5m or more below the ground surface and is likely to follow the surface topography and flow to the south. The bore logs show 'filling' (fills) consisting of dark to grey-brown medium grained sandy topsoil with occasional rootlets and some medium to coarse gravel inclusions, over medium to light brown sand that becomes denser and wetter with depth (see Figures 2.14-2.15). The fill deposits are between 0.5m (BH1) to 1.2m (BH2) thick over natural sand profiles and are likely to describe in a collective sense several different historical deposits created and deposited because of different activities.

The fill is likely to comprise highly mixed and disturbed sandy soils and sediments containing construction materials associated with the current Pavilion layout, and potentially historical archaeological features and deposits. Some of the boreholes report European artefacts in the form of glass and ceramic and building materials in the fills below current ground surfaces. Examples include the presence of 200 mm concrete fragments at 0.4m in BH3, some porcelain plate fragments at the same depth in BH4, and some coarse gravel and terracotta fragments at 1.0m in BH2.



Figure 2.14. Location of geotechnical investigations at Bondi Pavilion (Source: Douglas Partners 2015)

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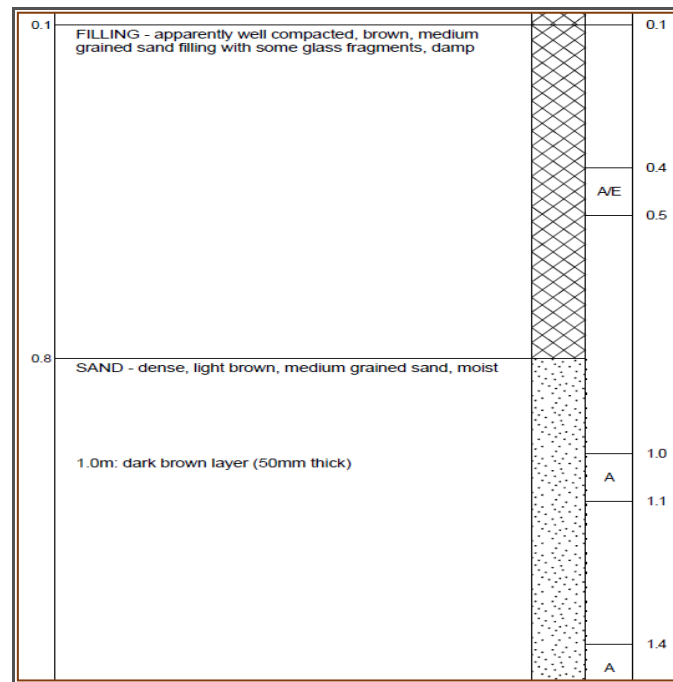


Figure 2.15. BH5 profile - showing buried dark brown loam layer below fill and separated above and below by natural sands (Source: Douglas Partners 2015).

One observation reported by Douglas Partners (ibid) in BH5 is noteworthy in so far as at a depth of 1.0m a 'dark brown layer' (50mm thick) is recorded below 20 cm of dense, light brown, medium grained sand and hence is well within the natural sand profile and is stratigraphically separated from the overlying fill by 0.2 m of sands. This discrete deposit could represent anything from a humic soil layer associated with former drainage (such as organic soil development within a channel or inter-dune swale) or a buried former land surface with a potential to retain Aboriginal objects.

2.7 Geotechnical information: Bondi Surf Club

Douglas Partners (2020) undertook a geotechnical investigation of the study area that included cone penetration tests and test pits (Appendix 1). The report included two cross sections of the subsurface stratigraphy of the sand body beneath the study area, one of which is provisionally identified in Figure 2.16. The stratigraphic profile is interpreted as (from base to top):

1. A basal sand described as very dense, potentially representing the Pleistocene bedrock-mantling dune geological formation (Qpbd).
2. These sands seem to be truncated by an unconformity (a period of erosion and therefore 'missing' stratigraphy or 'time') identified as the Pleistocene – Holocene Boundary?
3. A deposit of medium to very dense sands sit above the unconformity: these have been tentatively assigned to the Early and Mid-Holocene, making them part of the Holocene bedrock mantling dune geological formation (Qhbd).
4. These are overlain by a very loose to stiff silty sand and silty clay deposit that suggests an inter swale depositional environment (lagoon?).

5. The final episodes of dune formation are represented by two episodes of deposition: a very loose to loose silty sand in the north, and a medium dense sand to the south superimposed over the inter swale deposit. These deposits are also part of the Holocene bedrock mantling dune geological formation (Qhbd).
6. The final phase of dune building is truncated by the post-1788 (Anthropocene) deposits of the early 1800's through to the modern period, and are represented by landscaping earthworks, construction fills, services and building footprints.

For reasons explained in the following two sections, deposits 1, 3 and 5 above are all potential archaeological deposits (PAD) this . Deposit 4 has significance because it has a high potential to retain palaeoenvironmental signatures, but the basement footprint will not impact this deposit. The Holocene dune deposits are PAD through the entire depth of the stratigraphic column, as these fall well within the time frames for Aboriginal occupation of the Sydney area. The Pleistocene dune deposits are more problematical, since the key to separating PAD verses non-PAD is a chronological attribute. That is, anything dating to before 65-40,000 years ago (i.e. predating the accepted timeframe for the human settlement of Australia: see Section 2.3) will not be archaeologically sensitive (as far as we know today), whereas deposits falling into the 65-40,000 year time-frame or younger include buried land surfaces that are PAD (Figure 2.20).

Bondi Surf Club Desktop Geoarchaeological Assessment

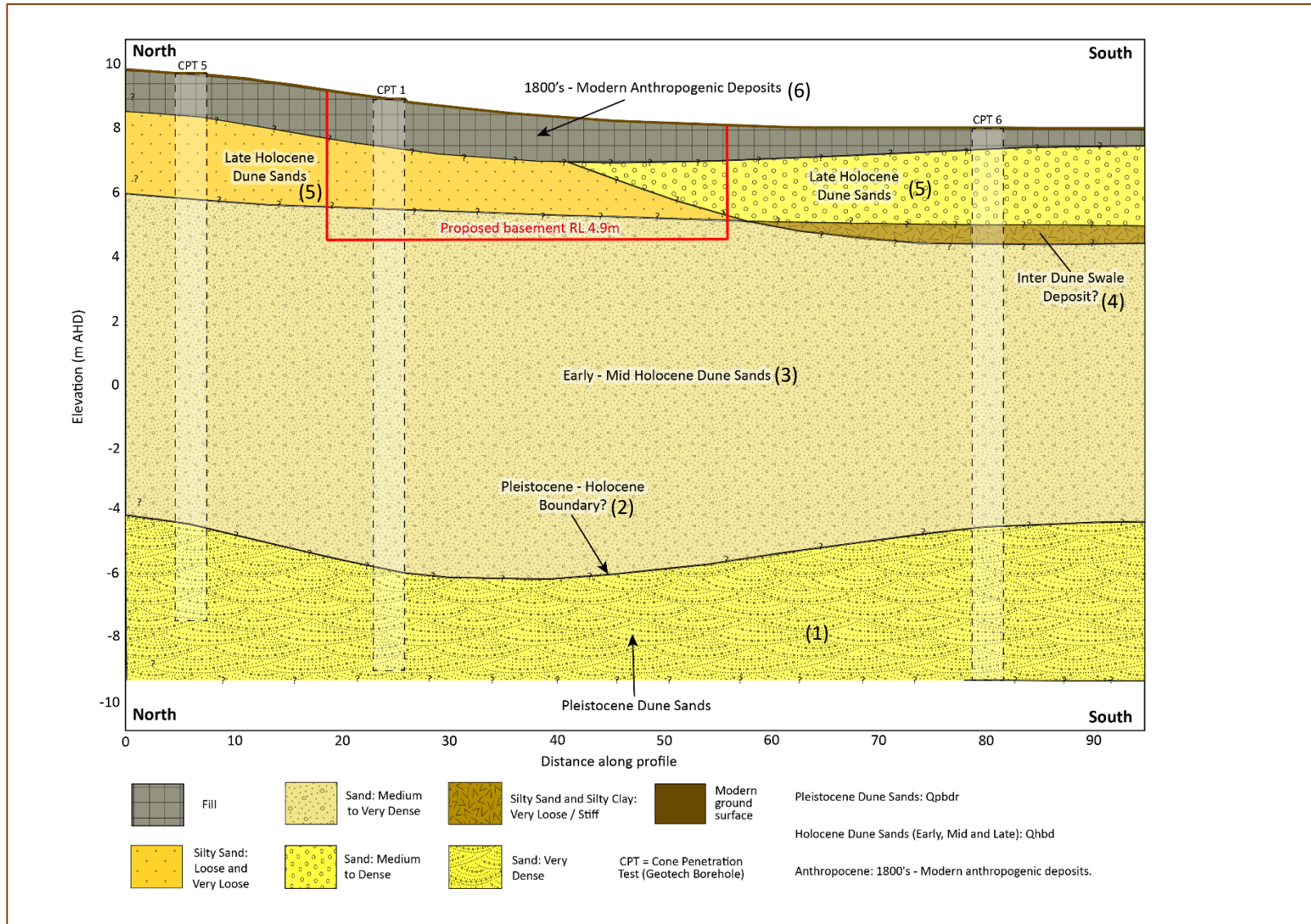


Figure 2.16. 2D stratigraphic model for the study area based on geotechnical data (Source: Douglas Partners 2020).

2.8 *Site Formation Processes*

A key factor in understanding the archaeological record is exploring depositional and post depositional processes and how they have impacted any extant archaeological objects (artefacts) and features, a method of enquiry referred to as ‘site formation processes’ (Schiffer 1983; Schiffer 1987; Stein 2001; see Barham 2008 for alternative term ‘taphonomy’ and Carey et al 2018 & 2019 for use of the term ‘deposit modelling’). Site formation processes encompass both natural and anthropogenic processes in the landscape and provide the framework for understanding the nature of the stratigraphic record. It represents the theoretical and methodological ‘inter-face’ between archaeology and the earth sciences (Stein 2001). This approach is the cornerstone of archaeological methods which investigate whether a deposit represents a primary (in situ) or secondary (reworked) archaeological context. From the perspective of archaeological (scientific) significance, a primary context that retains information on human activity such as a hearth is usually more significant than a deposit which includes gravels and artefacts reworked by sheet wash and redeposited at the base of slope, although there are always exceptions to the rule, for example a 30,000-year-old colluvial sediment at the base of a slope with artefacts.

Archaeological evidence of Aboriginal activities that have a high visibility in the landscape such as base camps or permanent villages are more likely to be located on landforms such as elevated river terraces or flat, benched areas on slopes protected from prevailing wind conditions. Conversely, there are locations more likely to reflect activity-specific but low-density archaeological signatures which have a lower detectability in the landscape such as gathering plant resources or hunting game on the periphery of estuaries, wetlands, mangroves, lagoons or creeks. Notable exceptions to this detectability are fish traps and weirs. Additionally, low density archaeological signatures are also more likely to be located in seasonally wet or permanently waterlogged areas, attributes that make them unlikely to characterise anything but short-term, activity specific visitation.

Using these examples as an analogy for the archaeological record generally, we can see Aboriginal settlement patterns will be dictated by environmental conditions such as the proximity of water, plant and animal resources, stone raw materials, drainage and elevation. These attributes are not however immutable and will change depending on factors such as prevailing climate, the hydrological cycle and sea levels. Changes in geomorphic systems due to climate, hydrology and sea levels can also initiate erosion and depositional processes and reshape the landscape and its resident sedimentary archive. Thus, these sedimentary environments (basins) are subject to processes that may destroy, redistribute, or bury archaeological features and objects and unravelling their depositional history is the cornerstone of archaeological method and theory.

This provides both a theoretical basis and informs methodological considerations when geoarchaeological and archaeological programs are being planned. It also reinforces the need for geoarchaeological approaches to be used ahead of testing programs and provides a landscape context for archaeological investigations. Many parts of the Sydney area have been stripped of soil or sediment cover, where these historically mobilised sediments have subsequently become part of colluvial and alluvial sediment blankets that are reactivated episodically. These soil geomorphological characteristics are quite common on what remains of the ‘natural’ Eastern Suburbs landscapes (and Australia generally) and understanding these accelerated cycles of episodic erosion and

deposition and what caused them in the post-Contact period is important because it has a direct bearing on the potential for archaeological and environmental signatures to survive (Allen 2013; Butzer and Helgren 2005; Cook 2019; Lawrence and Davies 2020; Eyles 1977; Mactaggart et al 2007).

Understanding the geomorphological setting(s) of a study area is important because it provides a guide into the range of potential site formation processes that may be relevant to a sites depositional history (e.g. Figure 2.17). It is also important from a landscape perspective to understand where in a catchment the study area is located as this will also have a bearing on the dominant geomorphic processes and the nature of sedimentary depositional environments. Investigating site formation processes is therefore important at all stages of the archaeological process because it informs research designs for archaeological test excavation strategies, and is used to map, distinguish and sample specific depositional and post-depositional events during excavation programs (Barham 2008; Czastka 2018; Goldberg and Macphail 2006). These are then selectively subject to laboratory analysis to refine the interpretation of landscape, environment, and people in the post-excavation phase (Goldberg and Macphail 2018; Stein 2001). In essence, site formation processes provide the filter through which we understand natural and anthropogenic contexts and provides the framework to understand archaeological sites in a dynamic, time transgressive landscape.

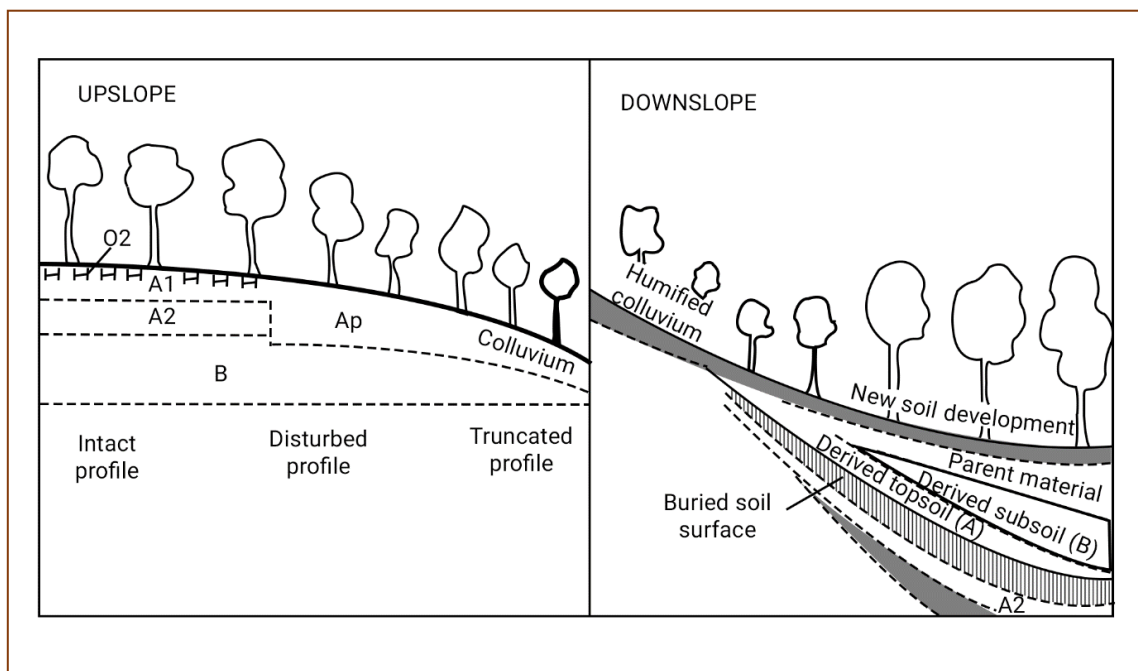


Figure 2.17. Simple model in cross section illustrating potential stratigraphic relationships between soils and sediments in a post-Contact landscape (Source: Butzer 1982: Figure 8-2).

2.9 Site Formation Processes of the Study Area

The final piece of the geoarchaeological jigsaw puzzle is to assess the evidence against general principles of site formation processes and devise an initial geoarchaeological site formation model for the study area, i.e. present a preliminary hypothesis to be tested in future stages of investigation. This is done within a framework of the long-term geological, geomorphological, eustatic (sea level rise or fall) and climatic factors that would have

controlled the nature, timing and position of Aboriginal settlement patterns and resource exploitation frameworks (Figure 2.18).

The model considers the gross depositional environments represented by the dune fields as they change based on factors such as the length of the coastal plain or the availability of sediments in the form of marine sands. The more fine-grained details such as the position and evolution of the palaeo-waterway of Bondi Creek, or the historical position of freshwater lagoons, cannot be incorporated into the preliminary model because there is insufficient detail in terms of subsurface stratigraphic architecture. However, the model is presented in its current form because it demonstrates how old land surfaces can be reworked, eroded or buried, and provides an illustration of the mechanisms that can accumulate depositional sequences several tens of metres thick, representing superimposed dune systems formed over geological time frames across the Bondi area. It also highlights the difficulty of 'detecting' archaeological and palaeoenvironmental signatures in deep, potentially complex sedimentary sequences like that of the study area.

Four Phases are identified for the model:

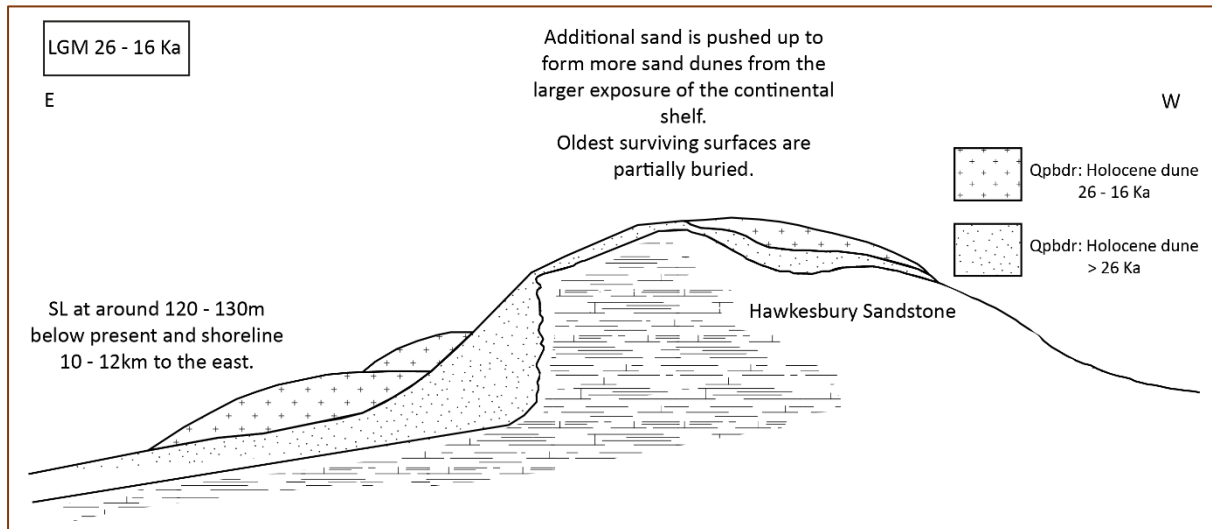
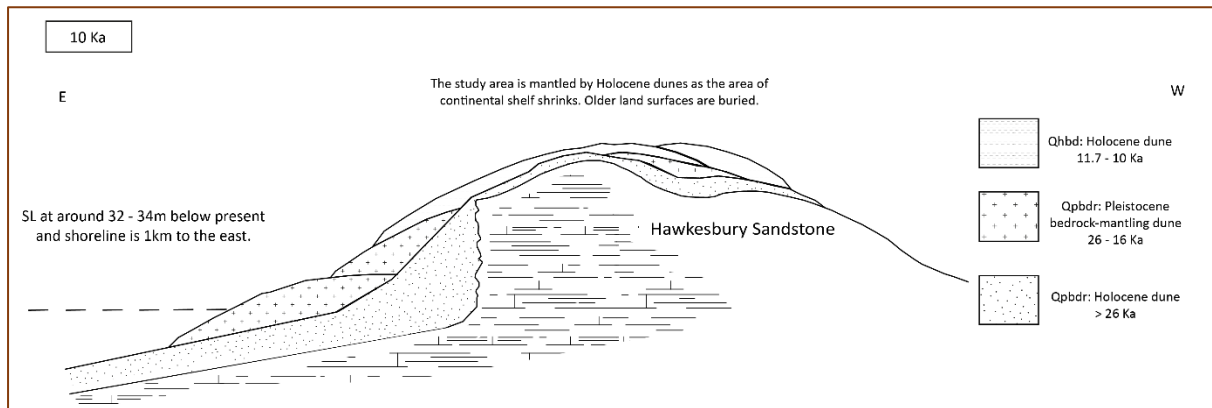
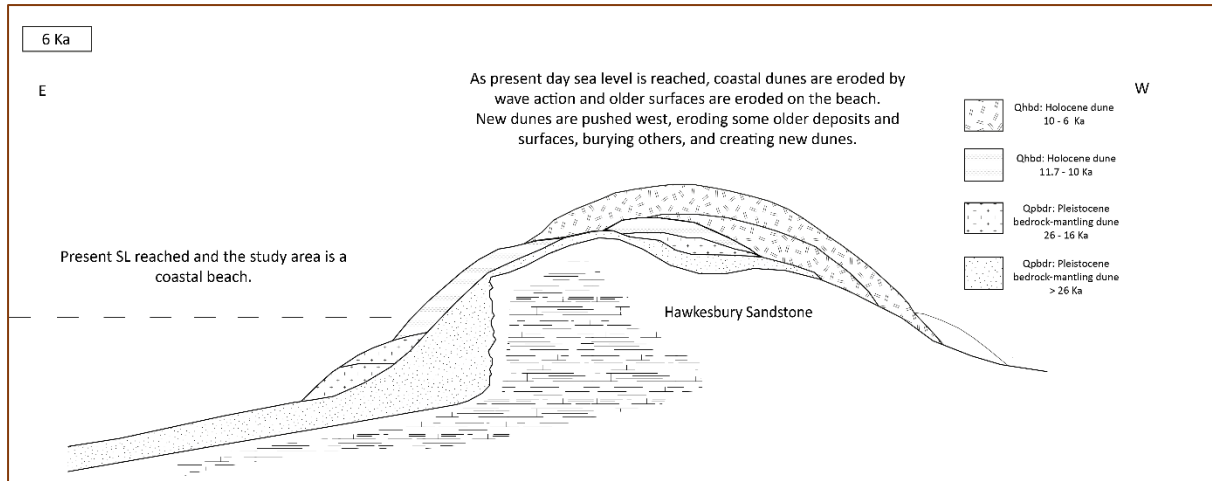
Phase 1: 31-26 Ka. The bedrock is mantled by marine sands reworked as dunes sometime during the Last Glacial cycle in the run up to the LGM. Sea levels are generally lower (at least 70 m) and there is a wide coastal plain on the exposed continental shelf stretching some 6-9 km eastwards.

Phase 2: LGM (26-16 Ka. Sea levels fall to their lowest levels at around 120-130 m below present sea levels and the windier, drier conditions instigate the most intense phase of dune building and reworking. The coastal plain is at its widest – some 10-12 kms – and provides a reasonably diverse and (potentially) well-resourced landscape with features like palaeo-waterways (Bondi Creek) and the Proto-Parramatta River valley.

Phase 3: 10 Ka. Sea levels have steadily risen in the aftermath of the LGM and the coastal plain has shrunk to being within a kilometre or so of the study area. The Bondi Creek Palaeo-waterway (and associated freshwater lagoons?) still provides a well-resourced landscape, although it's size and resource carrying capacity have decreased. Increased hydrological regimes (more rainfall) are potentially contributing to greater stability of Early Holocene dunes.

Phase 4: 6 Ka. Sea levels reach their present level and rise an additional 1-2 m above present-day levels. It is probable that the study area was located in the intertidal zone or was part of the beach during this phase (although evidence for these depositional environments has not survived), and earlier Holocene dunes were either buried, or reworked as beach sands within the embayment.

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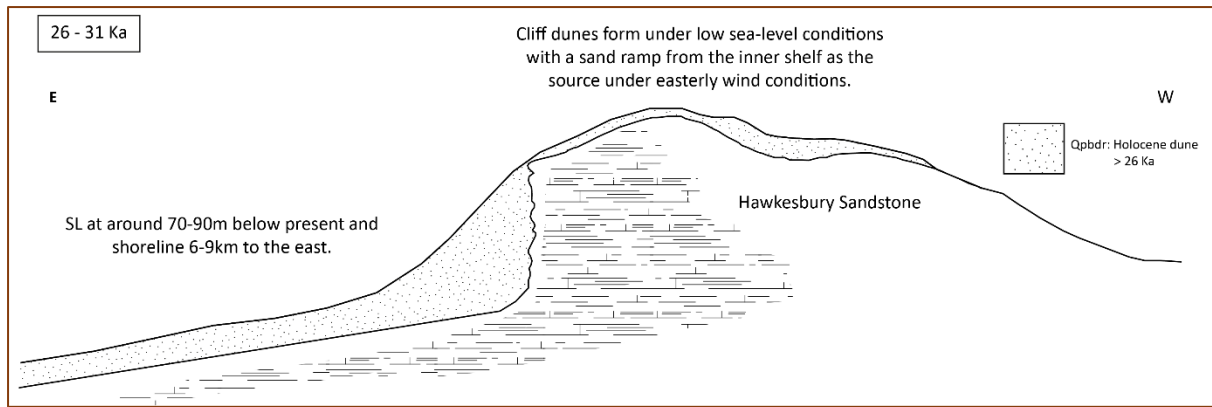


Figure 2.20. Simple geoarchaeological model in cross section illustrating potential stratigraphic relationships between sediments in four phases from oldest (bottom) to youngest (top) (Source: Modified from Figure 4: Thom and Oliver 2019).

3.0 Conclusions and Recommendations

3.1 Introduction

This final section provides an initial assessment of scientific sensitivity of PAD identified in the geotechnical investigations of the study area (Douglas Partners 2020). The scientific sensitivity ratings form the basis of the conclusions and recommendations.

3.2 Assessment of Scientific Sensitivity and Significance

There are no coherent, standardised, or accepted criteria for establishing archaeological (scientific) sensitivity or significance within the context of NSW's Aboriginal heritage guidelines or legislation, and archaeologists usually rely on numbers of artefacts, regardless of context, to drive the assessment of scientific values for open archaeological sites. In practice this means that 'lots' of artefacts are considered to be inherently more 'significant' than only a 'few' artefacts, with what constitutes 'few' versus 'lots' being a mutable quality (Barham 2008). This issue is further compounded by the fact that traditional archaeological approaches do not distinguish between soils or sediments and are therefore unable to distinguish an archaeological context (in situ) from a reworked context (secondary). This lack of engagement with the depositional history and stratigraphy of any PAD or archaeological site means that in practice archaeologists undertake far more testing than is justified or necessary because they do not understand the nature of the stratigraphic record that they are dealing with. As Barham noted in the strategic geoarchaeological study of Eastern Creek back in 2008 (iii):

'...as the area of undeveloped land on the Cumberland Plain continues to decline, and archaeological survey and salvage continue to rapidly acquire more data, a methodological "tipping point" has been reached in archaeological resource management. Acquiring more data by long-established methods will not represent best practice. Available information shows that the data already gathered through archaeological mitigation (survey, subsurface sampling and salvage excavations) need to be better contextualized. New 'best practice' protocols for acquiring archaeological information need to be developed. A key aim would be to devise methods for "nesting" the information from archaeological surveys and salvage work into enhanced and better integrated research and conservation frameworks. This report concludes that this new framework should build on, and utilize, a regolith science foundation.'

The current Heritage NSW guidelines and procedures enshrine the archaeological approach referred to as the 'methodological "tipping point"' by Barham, namely qualitative, subjective descriptions of deposits with little to no effort to establish stratigraphic frameworks or landscape contexts for archaeological sites.

The presentation of scientific significance criteria is an attempt to address this imbalance. Barham makes two very valid points in relation to this (2008: 128-129):

'A recognition that stratigraphic features and properties can represent archaeological sites of significance, or natural sites of significance independently of the presence or absence of lithic artefacts....'

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And,

...present approaches are so biased to recognizing archaeological site significance primarily in relation to lithic artefact presence, that related contextual aspects are virtually neglected. Logically, the principle of “salvage” should apply not only to the artefacts but to the remaining stratigraphy and landscape elements which are contextually related to those artefacts. This principle is poorly developed at present.’

Nature of deposit	Environmental Signatures	Archaeological Signatures	Significance Rating
Residual soils, mature transported soils, sand bodies, buried soils, palaeosols, weathered sediments, anthropogenic deposits/features	Pre-1788	Potential for in situ Aboriginal archaeology (primary contexts) Potential for reworked Aboriginal archaeology (secondary contexts)	High High to medium
Residual soils, mature transported soils, sand bodies, sediments, buried soils, anthropogenic deposits/features	Early Colonial 1788-1800 and/or 19 th Century	Potential for in situ Aboriginal and historic archaeology (primary contexts) Potential for reworked Aboriginal and historic archaeology (secondary contexts)	High Medium to low
Residual soils, transported soils, buried soils, sediments, anthropogenic deposits/features	Mix of early Colonial 1788-1800, 19 th Century and modern	Potential for in situ Aboriginal and historic archaeology (primary contexts) Potential for reworked Aboriginal and historic archaeology (secondary contexts)	High Medium to low
Anthropogenic deposits/features transported soils, sediments	Modern: 1900 onwards	Potential for in situ historical archaeology (primary contexts) Potential for reworked Aboriginal and historical archaeology (secondary contexts) Potential for no archaeological footprint	High to medium Medium to low
Truncated residual subsoil clays or historically/recently exposed bedrock	Geological	Potential for surface Aboriginal or historical archaeology (secondary contexts)	Low to zero

Table 1. Scientific significance criteria based on the nature and age of deposits and their environmental signatures and their relationship with potential archaeological signatures.

The scientific significance criteria are therefore based on soil and sedimentary attributes and the nature of the surviving palaeoenvironmental record, with potential archaeological attributes identified for each scenario (Table 1). For the current study we are assessing *sensitivity*, i.e. we are assessing *potential* values. To establish *significance*, the preliminary conclusions of a fieldwork program must be refined with a number of laboratory techniques that can confirm, refine, or refute a site’s depositional history. This is necessary as it provides the

scientific evidence to refine, reconsider or finalise a hypothesis(es), which would otherwise remain an unsubstantiated series of observations. This can be undertaken on archived samples and the results incorporated into an archaeological research design for a testing program or, used to inform an archaeological management plan on appropriate use and management of the extant archaeological resource.

The geological formations of the study area are assessed on their potential scientific sensitivity in Table 2.

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Geological Formation (Reference: Figures 2.4 and 2.16)	Dominant Modern Geomorphic Processes	Nature of exposures and deposits	Potential Archaeological (& Environmental) Signatures	Archaeological Potential	Scientific Sensitivity	Proposed impacts in this zone
1. Pleistocene bedrock mantling dune sands (Qpbdr)	None: completely buried beneath later sediments	None: subsurface only Stratified sediments	Surface artefact scatters	Low	Low	No
			PAD	High	High	
			Proxy data in PAD	High	High	
3 and 5. Holocene bedrock mantling dune sands (Qhbd)	Anthropogenic, aggrading and eroding	Truncated soils and sediments Stratified sediments	Surface artefact scatters	High	Low	Yes
			PAD	High	High	
			Proxy data in PAD	High	High	
4. Interdune swale/lagoon?	None: completely buried beneath later sediments	None: subsurface only Single sedimentary unit	Proxy data in PAD	High	High	No
Potential alluvial deposits (drowned river valleys) Not shown	Marine and anthropogenic	None: subsurface only Stratified sediments and transported soils	Surface artefact scatters	Zero	Zero	Unknown
			PAD	High	High	
			Proxy data in PAD	High	High	
Potential fluvial deposits (palaeo-waterways) Not shown	Marine and anthropogenic	None: subsurface only Stratified sediments	Proxy data	Low	High	Unknown
6. Anthropocene Deposits	Anthropogenic	Earthworks, landscaping, services, infrastructure and buildings	Historical PAD	Low	High	Yes

Table 2. Archaeological potential and scientific significance criteria based on the nature of site formation processes and environmental signatures. The archaeological potential refers to the probability of archaeological signatures surviving on the study area by geological formation. The probability is based on the observed attributes of the study area and takes into account the existing impacts and the nature of anthropogenic and geomorphological processes on or around the study area. Scientific sensitivity reflects the potential for palaeoenvironmental signatures in the form of proxy data to survive if the appropriate geology, sediments or soils are identified.

3.3 Conclusions

This geoarchaeological desktop assessment investigated the potential archaeological (scientific) sensitivity of an open area on the north side of Bondi Surf Club, Bondi Beach, NSW, by deciphering the available Quaternary geological mapping and analysing the relevant archaeological, geoarchaeological and geotechnical data from previous heritage assessments of Bondi Beach from a geoarchaeological perspective. It assessed the nature of the stratigraphic record on the study area and its potential to retain archaeological and palaeoenvironmental signatures (objects, archaeological features or proxy data) in potential archaeological deposits, and identified non-archaeological sediments such as earthworks or construction fills.

One of the intended uses of this desktop assessment will be to inform an archaeological cultural heritage assessment report that will subsequently guide the client in terms of their statutory requirements under the *NSW National Parks and Wildlife Act 1974* and *Heritage Act 1977*.

The report identified the following stratigraphic units (Figure 2.16):

- A basal sand buried several metres below current ground surfaces, potentially representing the Pleistocene bedrock-mantling dune geological formation (Qpbdr). These deposits are potential archaeological deposits (PAD) with high scientific values because of their potential to retain in situ archaeological and palaeoenvironmental signatures. The proposed impacts do not extend into this stratigraphic unit.
- A deposit of medium to very dense sands sit above these basal sands which have been assigned (stratigraphically) to the Early and Mid-Holocene, making them part of the Holocene bedrock mantling dune geological formation (Qhbd). Again, these deposits are potential archaeological deposits (PAD) with high scientific values because of their potential to retain in situ archaeological and palaeoenvironmental signatures. Proposed impacts will impact these deposits: see recommendations.
- These sands are subsequently overlain by a very loose to stiff silty sand and silty clay deposit that suggests an inter swale depositional environment (lagoon?) in the southern half of the study area. These deposits are unlikely to retain archaeological signatures, i.e. they are not PAD, but are important because they have a high potential to retain palaeoenvironmental signatures that can inform us about climate, hydrology and vegetation patterns. The proposed impacts do not extend into this stratigraphic unit.
- Two final episodes of dune formation are represented by a very loose to loose silty sand in the northern half, and a medium dense sand to the south superimposed over the inter swale deposit. These deposits are also part of the Holocene bedrock mantling dune geological formation (Qhbd). As such, these deposits are PAD with high scientific values because of their potential to retain in situ archaeological and palaeoenvironmental signatures. Proposed impacts will impact these deposits: see recommendations.
- The final phase of dune building is truncated by the post-1788 (Anthropocene) deposits of the early 1800's through to the modern period, and are represented by landscaping earthworks, construction

fills, services and building footprints. These deposits are highly disturbed and are assessed as non-PAD. Proposed impacts will impact these deposits: see recommendations.

3.5 Recommendations

The recommendations are based on the conclusions of the geoarchaeological assessment. These are:

5. The geoarchaeological assessment has concluded that there is scientific evidence for PAD and an archaeological testing program may be warranted. However, due to site constraints with the study area currently obscured by temporary amenities and additions, a staged approach is required for subsequent investigations. See schedule below (Section 3.6).
6. Therefore, we recommend that a geoarchaeological investigation is undertaken with the objective of recovering undisturbed boreholes, since there is a high probability that PAD may be located several metres below current ground surfaces, and traditional archaeological sampling techniques are unsuited to these conditions. This stage of works is planned for March 2022.
7. Stratigraphic, chronological and palaeoenvironmental analysis will need to be carried out on the deposits recovered from the boreholes to scientifically assess the preliminary hypothesis and ascertain whether the deposits are in fact PAD or non-PAD: see schedule below (Section 3.6).
8. Generating a 3D stratigraphic model based on the scientific analysis will provide the framework for informing where and how PAD can be assessed during an archaeological testing program. Conversely, the scientific analysis of the deposits may conclude that archaeological test excavation is not warranted, for example because all the deposits below fills pre-date the Aboriginal settlement of Australia.

3.6 Schedule of Works

Due to site constraints with the study area currently obscured by temporary amenities and additions, a staged approach is required for subsequent investigations.

The schedule is outlined in Table 3 below. This desktop assessment forms Stage 1 of the AHIP process. The temporary buildings will be removed over the next three months (yellow), after which ground access will become possible. We have allowed three months for the Stage 2 works to inform the AHIP process. Given the current constraints on the site, it is appropriate to have a staggered AHIP processes, allowing the DA approval to proceed, with Stage 2 of the process received as a condition of consent, and the conclusions of that stage of works will inform any subsequent archaeological AHIP requirements. Stage 2 works and any archaeological AHIP requirements will be completed prior the commencement of construction.

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Work Stage	May 2021	Jun 2021	Jul 2021	Aug 2021	Sep 2021	Oct 2021	Nov 2021	Dec 2021	Jan 2022	Feb 2022	Mar 2022	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022	Sep 2022	Oct 2021	Nov 2021	
DA Approval (PreDA submitted in 2018)	DA Approval																			
Grant Applications & Funding <u>Grants not available until DA approved</u>											Funding									
Detailed Design, Construction Documentation Builder Tender, Construction Certificate											Construction Preparation									
ACHA & AHIP Permit					ACHA Consultation															
<u>Archeological Investigations</u>					<u>AHIP Stage 1, Desktop Assessment</u>						<u>AHIP Stage 2, Ground Investigation</u>									
Temporary Buildings Removed, Ground Access Available								Temporary Buildings Removed												
Bondi Pavilion Construction Complete	Bondi Pavilion Construction																			
Bondi Surf Club Construction Begins																	Bondi Surf Club Construction			

Table 3. Proposed schedule of works.

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