4 CLIMATE, GEOLOGY AND SOILS

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Landscapes in Shoalwater Bay Training Area (SWBTA or the Area) are diverse, and in some parts breathtaking. A series of parallel mountain ranges running north-west to south-east break the country up into distinct areas, each characterised by various combinations of factors such as terrain, soil type, moisture conditions and vegetation. These distinct areas called Land Zones (refer to Chapter 6 ‘Forests, Woodlands and Freshwater Wetlands’ for a full description) owe much of their existence and diversity to the underlying geology. Geological rock units basically determine the nature of landforms, erosion and depositional patterns, and soil type. Climatic factors such as temperature and rainfall in turn influence the types of vegetation communities and animal habitats that occur.

The Great Dividing Range runs down the full length of eastern Australia. For the most part, it is close to the coast with small coastal catchments and limited sediment production. While the Great Divide loses much of its splendour in central Queensland, it still effectively separates the inland and coastal drainage systems. Central Queensland landscapes are unique in eastern Australia because the Burdekin and Fitzroy River coastal catchments extend so far inland. These large catchments contain high sediment sources and high potential for sediment transport, which have been important factors in regional landscape development (Jones 2006).

Geology and soils of the Area are not yet fully researched and therefore subject to a degree of interpretation. Reconnaissance scale (1:250 000) geological mapping over the Area was undertaken in 1965–66 by government geologists (Kirkegaard et al 1970; Murray 1975). Some follow-up geological and structural studies were undertaken on the metamorphic rocks in the northern portion of the Area between 1987 and 1993 (Fergusson et al 1990; Leitch et al 1994; Morand 1993). Geological interpretations reported here generally follow those of ABARE (1993). Willmott (2006) provides a good overview of local geology and the rocks and landscapes of the national parks of the region. Soil descriptions generally follow those of Gunn (1972).

CLIMATE

The climate of SWBTA is sub-tropical, with mostly summer rainfall. Temperatures are moderated by coastal influences, and range from a mean monthly maximum of 32°C in January to a mean monthly minimum of 10.5°C in July (ABARE 1993; Tunstall 1993). The average range between day and night temperatures changes marginally from 8°C in summer to 10°C in winter. Clear, still nights produce heavy dews throughout the year, particularly in coastal areas. These same conditions at times produce fogs and frosts.

Major influences affecting rainfall in the Area are prevailing south-easterly winds, storms from the west in summer, and cyclones. Moisture-laden onshore winds originate either from high pressure regions moving across the south of the continent from west to east, or from easterly moving upper atmosphere depressions or troughs in the local region. Cyclones move down the Queensland coast from January to March after forming in tropical waters. They influence the central Queensland coast region on average every two years, bringing intense rain and strong winds. Both thunderstorms and cyclones occur sporadically, resulting in very high annual variability in rainfall. Spatial variability in rainfall across the Area can also be significant due to localised rainfall events.

Moisture laden air in south-easterly winds from the sea is driven upwards by these mountain ranges and cooled, causing precipitation. This orographic effect is most pronounced in the eastern parts, with highest rainfall occurring around Mount Parnassus in the south-east corner of the Area. The high mountain ranges in the north-west including Double Mountain and Mount Phipps also produce rain, creating a rain shadow over the western plains. There is a strong rainfall gradient dropping from east to west across SWBTA. Bureau of Meteorology precipitation data is available from rainfall gauges at Samuel Hill airfield since 2001 and from Williamson airfield since mid-
In 2006, the total annual rainfall recorded at Samuel Hill and Williamson was 1,338 mm and 662 mm respectively, and in 2007 it was 1,528 mm and 578 mm respectively. These figures illustrate the disparity in rainfall received between eastern and western parts of the SWBTA.

Rainfall received in SWBTA also varies considerably between years. For example, at Samuel Hill only 725 mm was received in 2001 compared to the 1,528 mm received in 2007. Such variations in annual rainfall are largely due to influences of the El Niño–Southern Oscillation (ENSO), which is a variation in normal sea surface temperatures in the equatorial Pacific Ocean. Prevailing Pacific Ocean trade winds drive surface waters west along the equator, resulting in the accumulation of warm waters north-east of Australia in the western equatorial Pacific. The warm ocean conditions heat the moist air above it, eventually producing clouds and rain.

A calculation called the Southern Oscillation Index (SOI) is used to gauge the status of the ENSO through time. It is derived from the monthly fluctuations in air pressure difference between Tahiti and Darwin. Sustained negative values of the SOI indicate El Niño conditions, which warm the central and eastern tropical Pacific Ocean, weaken the Pacific trade winds, and reduce the rainfall over eastern and northern Australia. When the SOI reaches sustained positive values, La Niña conditions prevail. These conditions produce stronger Pacific trade winds, with warmer sea temperatures and an increased probability of higher than normal rainfall in northern Australia (BOM 2008). It has been calculated that when the SOI is more than +5 (La Niña conditions), the mean annual rainfall received at St Lawrence to the north-west of SWBTA is 986 mm, reducing to 653 mm when the SOI is less than -5 (El Niño conditions) (Clewett et al 1991). Fluctuations between El Niño and La Niña events typically occur every two to seven years (DCC 2007).
Geologically, the history of the eastern side of the Australian continent is complex as it grew by accretion over some 400 million years, from about 570 to 200 million years ago. During this time, and east of a line roughly between Adelaide, Broken Hill and Cloncurry, various sedimentary, volcanic and metamorphic rocks were added to Australia’s ancient (Precambrian) ‘core’. These additions were created through the continual interaction of lighter density rocks on the west with more dense rocks of the oceanic crust as they were dragged beneath the continent. Tectonic stretching alternated with compression at different places and times along the growing continental margin, with eruption of volcanic lavas and deposition of sediments. The times of compression involved crumpling, folding and uplifting of sediments, metamorphism through pressure and heat, and intrusion of molten granites (Willmott 2006). By about 50 million years ago the meridional line of tectonic activity between continental crust and oceanic crust had shifted well to the east, to a position running north-east of New Zealand. The eastern margin of the Australian mainland, marked roughly by the edge of the continental shelf, has remained largely unchanged since that time.

Geologists identify the western two-thirds of Australia as the Precambrian Shield, and rocks in the eastern third as the Tasman Mobile Zone or Orogen. Within the Tasman Orogen, major compression and granite-injection episodes or orogenies operated at different times and are given appropriate geographical names. Most rocks of eastern central Queensland, including SWBTA, are part of the New England Orogen, which began to grow during the late Silurian period, about 420 million years ago (Willmott 2006). This major belt of folded rocks covers the eastern parts of Australia from about Bowen in north Queensland to the central New South Wales coast. To its immediate west is the Sydney-Bowen Basin, which was forced to subside due to pressure in early Permian times about 290 million years ago.

Between 375 and 320 million years ago, during the late Devonian to mid-Carboniferous periods, a volcanic chain called the Connors-Auburn Volcanic Arc developed above the line of oceanic crust that was being pushed downwards on its western edge. From this line of volcanic mountains, large volumes of sediments were sent down underwater canyons to the deep ocean floor beyond the continental shelf. These deep-water sediments were formed from overlapping layers of sand, silt and mud, and geologists map these rocks within the Wandilla Province (characterised as rich in volcanic detritus) and the Shoalwater Province (rich in quartzose lithics).
**TABLE 4.1**

Descriptions and ages (in chronological order) of the geology of SWBTA

Source: Queensland Department of Mines and Energy

<table>
<thead>
<tr>
<th>Geological Unit</th>
<th>Description</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qe</td>
<td>Coastal tidal flats, estuarine channels and banks, mangrove flats, supratidal flats, salt pans, swamps and grasslands - mud and sandy mud, minor sand and gravel</td>
<td>HOLOCENE</td>
</tr>
<tr>
<td>Qd</td>
<td>High parabolic sand dunes - quartz sand</td>
<td>PLEISTOCENE</td>
</tr>
<tr>
<td>Qr</td>
<td>Colluvial and residual deposits - clay, silt, sand, gravel and soil</td>
<td>QUATERNARY</td>
</tr>
<tr>
<td>Qa</td>
<td>Floodplain alluvium - clay, silt, sand, gravel,</td>
<td>QUATERNARY</td>
</tr>
<tr>
<td>Peninsula Range Volcanics</td>
<td>Pyroclastic crystal tuff, rhyolite flows, agglomerate</td>
<td>EARLY TRIASSIC</td>
</tr>
<tr>
<td>Double Mountain Volcanics</td>
<td>Dacitic crystal tuff, lithic, vitric and lapilli tuff, agglomerate, minor siltstone</td>
<td>EARLY TRIASSIC</td>
</tr>
<tr>
<td>Latite intrusions</td>
<td>Latite</td>
<td>LATE TRIASSIC</td>
</tr>
<tr>
<td>Diorite intrusions</td>
<td>Quartz diorite, granite</td>
<td>LATE TRIASSIC</td>
</tr>
<tr>
<td>Pyri Pyri Granite</td>
<td>Muscovite-biotite granite, hornblende-biotite adamellite, biotite-hornblende granodiorite, porphyritic dacite</td>
<td>LATE TRIASSIC</td>
</tr>
<tr>
<td>Bayfield Granite</td>
<td>Leucocratic biotite granite, biotite-hornblende adamellite</td>
<td>LATE TRIASSIC</td>
</tr>
<tr>
<td>Shoalwater Formation</td>
<td>Quartzose sandstone, mudstone, local quartz-muscovite-biotite schist</td>
<td>CARBONIFEROUS</td>
</tr>
<tr>
<td>Townshend Formation</td>
<td>Massive amphibolite, quartzite and mica schist</td>
<td>DEVONIAN - CARBONIFEROUS</td>
</tr>
<tr>
<td>Broome Head Metamorphics</td>
<td>Quartz-rich, garnetiferous, migmatitic gneiss, amphibolite and quartzite, common granitic and pegmatitic veins and segregations containing muscovite, garnet and tourmaline</td>
<td>DEVONIAN - CARBONIFEROUS</td>
</tr>
<tr>
<td>Wandilla Formation</td>
<td>Mudstone, lithic sandstone, siltstone, jasper, chert, slate, local schist</td>
<td>LATE DEVONIAN - CARBONIFEROUS</td>
</tr>
<tr>
<td>Sabina Point Schist</td>
<td>Quartz-mica schist with a single planar foliation (Shear Zone)</td>
<td>LATE DEVONIAN - CARBONIFEROUS</td>
</tr>
</tbody>
</table>
The New England Orogen then underwent a major episode of change (orogeny) from late Permian to mid-Triassic times between 265 and 235 million years ago. The oceanic sedimentary rocks were tightly folded and thrust westwards over sections of the volcanic arc, undergoing variable metamorphism before being exposed at the surface as high mountain ranges that were worn down by erosion. Components of these metamorphosed sedimentary rock formations are prominent underlying structural components of SWBTA and include mapped and named Broome Head Metamorphics, Sabina Point Schist and the Townshend, Wandilla and Shoalwater Formations (Figure 4.1; Table 4.1).

After the late Triassic period about 200 million years ago much of the continent became stable, and slow subsidence of broad sedimentary basins was the new tectonic style (Willmott 2006). It was not until the late Triassic period between 250 and 200 million years ago that further major geological change occurred in the region. The eastern margins of the continental plate again came under pressure causing the fracturing and breaking of rocks. This resulted in the emplacement of igneous rocks in SWBTA through both development of a line of volcanoes, and intrusion of granites in regions of the New England Orogen. Willmott (2006) interprets the Cretaceous-age (120 to 100 million years old) Whitsunday Volcanic Province extending into SWBTA and represented by the Peninsula Range and Double Mountain Volcanics. Published geological maps however indicate the age of these volcanics is poorly constrained and may be early to late Triassic in age (250 to 230 million years).

The Peninsula Range Volcanics includes the high peaks of Mount Westall and Notch Mountain on the Peninsula Range, Mount Flinders, Mount Solitude and Cliff Point. At 742 metres, Double Mountain in the west is the highest peak in SWBTA and is formed from Double Mountain Volcanics.

Granites in SWBTA probably intruded the earlier sedimentary rocks and volcanics during the Triassic period, between about 230 and 200 million years ago. They include an area of Bayfield Granite in the south-east corner of the Area forming the Mount Parnassus complex of peaks and ranges. Larger areas of Pyri Pyri Granite form parts of the high western spine of SWBTA including Mount Phips. Granites are intrusive rocks formed by the melting of parts of the earth’s crust. In the central coast region of Queensland the heat came from both compression and extension of the continental plate during interactions with the oceanic plate to the east (Willmott 2006).

The geology of the remaining parts of SWBTA consists of sediments (fluvial deposits, wind-deposited sands) and coastal deposits of various ages. The oldest and largest areas of the fluvial deposits were laid down during the late Tertiary and early Quaternary periods and consist mostly of clay, silt, sand and gravel with soil at the exposed surface. These sediments were mostly eroded from the igneous and metamorphic formations of surrounding areas, and carried downstream in rivers and streams. The youngest areas of sediment in SWBTA include coastal sand dunes and tidal flats, mangrove wetlands and salt marshes. Coastal sand dunes cover substantial areas of the older rocks up to 13 kilometres inland from today’s coastline.
GEOLOGY OF SWBTA (Source: DME 2008)

Geological Units

- Sedimentary
  - Oe
  - Od
  - Qr
  - Oahist

- Igneous
  - Peninsula Range Volcanics
  - Double Mountain Volcanics
  - Latite intrusions
  - Diorite intrusions
  - Pyl Pri Granite
  - Bayfield Granite

- Metamorphic
  - Shoalwater Formation
  - Townshend Formation
  - Broome Head Metamorphics
  - Wandilla Formation
  - Sabina Point Schist

Geological Faults

- Fault accurate
- Fault approximate
- Fault concealed

Note: See Table 3.1 for explanation of Geological Units

FIGURE 4.1
FIGURE 4.2

PARABOLIC SAND DUNES OF TOWNSHEND ISLAND SECTOR, SWBTA

- Dune ridge crests
- Roads
FIGURE 4.3

PARABOLIC SAND DUNES
OF GIBRALTAR SECTOR,
SWBTA

Dune ridge crests

Kilometres

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FIGURE 4.4

PARABOLIC SAND DUNES OF FRESHWATER SECTOR, SWBTA

- Dune ridge crests
- Roads

Freshwater Swamp

Kilometres

0 1 2
PARABOLIC SAND DUNES OF DISMAL SECTOR, SWBTA

- Dune ridge crests
- Sinkholes
- Shallow dune lakes
- Roads

FIGURE 4.5

Kilometres

Dismal Swamp

Freshwater Swamp

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SAND DUNES

From north to south, relict (vegetated) parabolic dunes occur in four sectors of SWBTA: Townsend Island, Gibraltar, Freshwater and Dismal Sectors. Many dunes in Dismal Sector are linked with those in the northern end of Byfield National Park. Each of the Sectors has characteristic dune patterns related to size, variety and associated dunefield forms. Figures 4.2–4.5 show the traces of the dune ridge crests which reveal the distribution of parabolic dunes in each Sector. Except for the northern part of Gibraltar Sector and Freshwater Sector, the many relict parabolic dunes are typical of those that develop in a relatively thin veneer of sand that has buried a rocky surface. These dunes were formed from sand supplied initially from the sea and also from later episodes of re-working.

The beach ridge complex of the Clinton Low Lands is a fine example of a prograded (receded) coastline of low relief built by excess sand arriving at a favourable site for accumulation.

The sand dunes in SWBTA are highly significant in a national context (Commonwealth of Australia 1994). They are excellent examples of parabolic and parallel dune formations, and remain in an unmodified condition.

Perforated Point

Iron nodules in sand dunes
TOWNSHEND ISLAND SECTOR

The smallest development of parabolic dunes is in the far north of Townshend Island Sector (Figure 4.2). Significantly, the upwind end of the dune field does not extend from the rocky coastline. This is indicative of cliff-top dunes consisting of a relatively thin veneer of sand that has been cut off from their original beach source. There were probably ocean currents that directed sand onshore at this remote location. Most of the dunes are elongate and the maximum length is around four kilometres. This dune field is quite isolated and some 17 kilometres north of the nearest dunes of Gibraltar Sector.

GIBRALTAR SECTOR

In the main part of Gibraltar Sector relict parabolic dunes extend almost 10 kilometres to the northwest from the upwind (south-east) end of the dune field (Figure 4.3). Conditions appear to have been very favourable for the development of several generations of dunes in a hinterland beyond a curvilinear coastline almost at right angles to the predominant south-easterlies. However, the largest continuous ridge is a little more than three kilometres long. Many of the parabolic dunes in the Gibraltar Sector dunes have a tongue-shape, typical of parabolic dunes in this setting. On the south-western side of the main part of the dune field the trailing ridges are distorted where they encroach onto rocky ridges. Bare sand areas appear in the south-eastern end of the Gibraltar Sector and are associated with small parabolic dunes north-west of an abandoned shoreline, 400 metres inland from today’s coastline. In contrast to this extensive area of large dunes in the south of the Sector, the various relict parabolic dunes in the northern part developed along a strip less than four kilometres wide. This relatively limited extent appears to be connected in part with a shoreline trending NNW-SSE.
Parabolic dunes are sand dunes distinguished by having, in plan view, paired linear ridges joined through a U- or V-shaped ridge at the downwind head. They are formed where there is an abundant sand supply, a dominant wind from one direction and sand-trapping vegetation. Parabolic dunes of various sizes are common in coastal and coastal hinterland settings where geological conditions have delivered continual supplies of sand for transport by the sea, waves and onshore winds.

A series of vegetated linear ridges and inter-ridge swales (linear depressions) can build up in a coastal area behind a shoreline receiving a high supply of sand. Because the ridges originally formed as linear dunes behind the beach, the ridges and swale sequence is also called a beach-ridge complex. Scoop-shaped erosional hollows called blowouts, from which the eroded sands are deposited as downwind mounds, can break continuity of the sequence. As the erosion–deposition activity continues each blowout is enlarged and the sand mound assumes a distinctive U- or V-shape. Sand is continually trapped by vegetation in the straighter paired ridges to each side of the hollow and the blowout develops the well-recognised form of a parabolic dune (see diagram). Sand at the mobile head area is unvegetated until the parabolic dune becomes fully stabilised.

On many coasts where the relict (vegetated) parabolic dunes are small (up to 500 metres long) their immediate source of sand from older ridges and swales is very evident. However, for most long parabolic dunes (11 kilometres seems to be the world record) in coastal hinterlands there is no direct connection to upwind beach and ridge-swale systems. These dunes grow in size through the progressive removal of sand from the deflation corridor (see diagram) between the paired ridges, its transport downwind and trapping in the ridges near the head area. Dune length and ridge size is determined by wind strength and the thickness of sand available for re-working. The depth of deflation in the intra-dune corridor may be limited by a permanent basement of rock or cemented sand or it may be seasonally variable (groundwater in wet and dry seasons).

Parabolic dunes that have trailing ridges more than three times the distance between the paired ridges are called ‘elongate’ and ‘very elongate’ if the ratio is 10:1 or more. If ridge height is greater than 20 metres above the local surface the parabolic dune is considered to be ‘large’.
In a dunefield of parabolic dunes it is common to find one dune cannibalising the sand of a neighbour, stopping its potential for growth. The head area of a parabolic dune may advance so rapidly that, in this wind drift form, the curved connecting ridge is lost. Temporary stabilisation of a parabolic dune under vegetation followed by re-mobilisation of sand from the inner deflation corridor can yield a dune with a double-ridge. If sand is re-mobilised several times from within the deflation corridor, the result can be a series of small parabolic dunes nested within the larger dune.

Depending on the geological setting, parabolic dunes can lose sand at the downwind end by spilling into the sea or decapitation by marine processes. The upwind ends of trailing ridges can be trimmed by wave erosion associated with beach realignment or rising sea level.

Dunefields that have been mobile, over a long time or undergone many episodes of re-mobilisation, can have several generations of parabolic dunes. Some common features such as size, position and orientation may identify the different generations. However, because re-working of sand is such a fundamental process in dunefields it would be misleading to identify one parabolic dune as being formed in one ‘event’. Drilling in parabolic dunes has shown that most ridges have at least one ‘core’ of an older dune. This is especially so if the parabolic dune is large and/or elongate.

FRESHWATER SECTOR
Parabolic dunes of several episodes dominate the sandy, elongated peninsula of the Freshwater Sector (Figure 4.4). In geomorphological terms this small peninsular (eight kilometres long and two kilometres wide) is a tombolo—a narrow sand spit linking a rock island with the mainland shore. The relict dunes are oriented at an angle to the shoreline which trends almost north-south. In this narrow development the many dune advances show most clearly a generic link with sand sourced along a shoreline exposed to persistent onshore winds. Some of the dunes in the western side have multiple heads; but V-shaped single dunes are more common and most are less than 500 metres wide. The longest trailing arm is about two kilometres long. In the south-west, the head of one dune was lost to the Port Clinton estuary leaving paired trailing arms about 700 metres apart. The southern end of the Freshwater Sector dunes commences where sand on the tombolo is first exposed to dune-forming winds from the south-east not interrupted by the rocky headland of Cliff Point, separating it from the Dismal Sector.
DISMAL SECTOR

The Dismal Sector contains the largest development of relict parabolic dunes and associated features in SWBTA (Figure 4.5). Short bays between rocky headlands are typical of most of the northern part of the Sector and total dune extent inland from the shoreline is almost 13 kilometres. The longest unbroken dune ridge of seven kilometres is here, and dunes reach elevations of 200 metres above sea level. As with dunes in the Townshend Island Sector, most of these are cliff-top dunes but here they are characterised by large, flat, open forms with multiple-heads. One in the north shows prominent double-ridges around most of the head area extending for about five kilometres.

In the southern part of the Dismal Sector the downwind (inland) end of the dunes is almost 10 kilometres from today’s coastline. Here, the upwind ends are actually in the Byfield National Park. A distinctive and significant feature of these southern dunes is the complex dune nesting. The hosting dune is up to two kilometres wide but most of the nested younger dunes occur in the southern half of its deflation corridor. This clustering is the most concentrated of any Australian dune field. Some of the broad dunes in Byfield National Park also exhibit multiple ridge movements and have nested dunes in the deflation corridor. However, the nesting in Byfield National Park is a little less dense than in SWBTA.

Three sets of small parabolic dunes also occur in the Dismal Sector. Two of these are located immediately inland from short sections of beach immediately south of Cliff Point (One Mile Beach) and Cape Manifold. The third set is located at the northern end of Five Rocks Beach that the Dismal Sector shares with Byfield National Park. Between the northern and southern development of parabolic dunes in the Dismal Sector is a spectacular low-relief deflation surface some two to three kilometres wide, colloquially known as ‘Solitude Valley’. In geomorphological terms this surface is a large inter-dune corridor and probably is a remnant of previous dune advances and erosion. The Three Rivers, a series of shallow vegetated streams, flow from the dunes to the coast. These streams are typical of drainage lines that developed in Pleistocene-age sandy terrain on sand islands like Fraser Island. They maintain a strong water flow even during the most prolonged droughts, but the sub-surface hydrology responsible for this flow is not well understood.

A notable feature of the deflation surface is a group of five, shallow dune lakes, generally 60–80 metres above sea level. The deflation surface supporting these lakes links up with other deflation surfaces in the west and south. The largest dune lake has a characteristic pear shape, with the head to the southeast and a long axis of about one kilometre. Its north-eastern side was once curvilinear but is now straight as a consequence of infilling by the longest, straight trailing dune arm in SWBTA (Figure 4.5). This type of lake is very common in the extensive dune fields of tropical north Queensland (Cape Flattery and Shelburne Bay). However, except for a single dune lake in Byfield National Park, the five Dismal Sector lakes are the only dune lakes in all the dune fields between Fraser Island (300 kilometres to the south-east) and Cape Flattery (1 000 kilometres to the north-west).
Dating of many coastal dunes suggests that abundant sand becomes available at and/or soon after periods of geologically high relative sea level. Consequently, Wilmott (2006) identified three distinct ages in the parabolic dunes of central Queensland—Pleistocene, around 120,000 years ago; late Pleistocene through early Holocene, 10,000 to 6,000 years ago; and during the past 6,000 years. However, dune sands as old as 730,000 years have been dated in the Cooloola sandmass has shown that there is no simple pattern to dune emplacement (Tejan-Kella et al. 1990), and Lees (2006). In part, there is no one-for-one link to times of high relative sea level because once sand is on a land surface its movement by the wind is related to climatic variations and broader geological factors rather than sea level position. The dating of dune emplacement becomes even more complex when re-working, cannibalisation and core remnants are taken into consideration.

The age of different dune episodes in SWBTA is an estimate based on broad geological models and the translation of ages from other Queensland dunefields. Until research to accurately date the dunes is completed, soil characteristics are probably the best indicators of general ages. In the Dismal Sector the deflation surface, with dune lakes and southeast-drainage stream, is associated with white, leached sands supporting low heath vegetation. Other parabolic dunes and associated inter-dune and intra-dune areas in the western parts of some Sectors, especially those with extensive development of larger dunes, also have thick white sands at the surface. These locations, especially those dunes with broad ridges of gentler slopes, carry sand deposited in the Pleistocene. The white sands are indicative of intact deep siliceous podzols or are partly truncated A2 horizons. Alternatively, the white sands of dunes with steeper side slopes probably represent younger accumulations of sand (though still possibly Pleistocene in age) stripped from the upper parts of deep podsol profiles.

Most of the parabolic dunes of middle size and steep side slopes have soil profiles indicative of dune formation across the later Pleistocene and early Holocene. Depth to the B horizon would be less than five metres in an undisturbed site on a ridge crest. Many of these dunes are likely to have older cores that were buried during subsequent sand advance. The younger dunes may be yellow brown soils with little profile development—they support eucalypt forests and woodlands.

Older small parabolic dunes inland from the abandoned shoreline of the Gibraltar Sector and other sets close to the coast may have incipient podzols, but are generally yellow brown in colour. Almost all of these dunes were developed since relative sea level in the mid-Holocene settled near today’s position. Some of their composite sands were newly delivered by the sea. Other dunes formed from re-worked older dunes immediately behind the shore. Nutrients are readily available so these dunes support tree development and colonising scrubby plants typical of windy exposed coasts.

CLINTON LOW LANDS

Clinton Low Lands (Cleo Island) is a well-developed beach ridge and swale sequence with a kidney shape in plan view. Research to date, mostly associated with mineral exploration, suggests the complex of parallel and curvilinear ridges is fully Pleistocene in age. However, it may have a significant Holocene component including sets of dunes and blowouts on the eastern margin. Deposition in the Pleistocene would have occurred during the Eemian Interglacial (125,000 years ago) when relative sea level was close to today’s, and possibly before the dunes in the Freshwater Sector were formed cutting off the sand supply. Clinton Low Lands is significant because it is one of three locations where Pleistocene beach ridge sequences are well developed in Queensland. Pleistocene beach ridge complexes occur on Fraser and Bribie Islands but these were formed under temperate climatic conditions. Establishing the age span of beach ridges and dunes would be an important complementary objective of research into dune development in SWBTA.
SINKHOLES

Numerous sinkholes of various sizes occur in the eastern sand dunes of SWBTA. They are conical, with sandy sloping surfaces (up to 20 degrees), up to 30 metres deep and 100 metres across. Although their underlying geological structures are uncertain, they are likely to be sand-filled depressions caused by rainwater and groundwater removing soluble minerals from the underlying rock (ABARE 1993). In SWBTA the rock is more likely to be an iron-based rock-soil material such as laterite (ferricrete) rather than limestone. However, if the sinkholes are entirely restricted to the oldest dune areas, the sinkholes could be related to collapse of iron-rich units within the weathered soil profiles of the sand rather than of underlying laterites in weathered rocks. Sinkholes with significant infilling of sand, like those in elevated dune terrain of SWBTA, appear to be rare features world-wide.

The sinkholes recorded in the sandy terrain of Cape York Peninsula, for example, are different because they occur within low elevation, low-relief beach ridges. The larger sinkholes in SWBTA have permanent freshwater springs emanating from their floors and support rainforest communities, often dominated by emergent piccabeen palms Archontophoenix cunninghamiana (Melzer et al 1993). Even very small sinkholes contain high soil moisture levels and support denser vegetation than in the surrounding dunes.
Sinkholes are topographic depressions that usually form through the development of voids (caves, tunnels) that collapse as soluble minerals are dissolved by rainwater seeping down fractures and by groundwater moving through a rock mass. The rock types that commonly host sinkholes include limestones, impure limestones and other carbonate-based sedimentary rocks; and salt-bearing or gypsum-bearing sediments. Surprisingly, even some silica-rich rocks like quartzites and iron-bearing rocks and deeply weathered soils (ferricrete, laterite) can develop sinkholes (Twidale 1987; Wray 1997).

Sinkholes are one of a variety of landforms and features peculiar to karst terrain. If developed on rocks other than carbonates, the same collection of landforms and features is called pseudokarst. Usually, the original form of the sinkhole is masked by the later collapse of roof and sidewalls and through infilling by slope-wash, soil materials and other sediments moved in by water and wind. The dissolving water may sometimes be evident as permanent free water in the bottom of the sinkholes; these are called cenotes in the limestone karst of central America. More commonly, the groundwater appears as a permanent spring, or a seasonal wet place if the groundwater table has more extreme fluctuations.

In Australia, sinkholes are known from the Tertiary limestones of the Nullarbor dolines (caves). Common, but less well known, are sinkholes hosted in Tertiary laterites and Precambrian quartz sandstones in the Northern Territory and Western Australia. When not obscured by later fill, these sinkholes are up to 50 metres across and 15 metres deep. However, sinkholes all have raised floors from accumulated debris, so depth below surrounding surfaces is uncertain. Much smaller sinkholes are formed in laterites near Bundaberg (Robertson 1979) — the nearest known to SWBTA.

Another place in tropical Queensland with distinctive sinkholes in sandy terrain is the Pennefather-Duyfken area of western Cape York Peninsula. As with sinkholes in SWBTA their exact origins are not fully established, in part because of the obscuring sand cover. Nevertheless their connection with groundwater action is clear. Sinkholes are also known in the Cape Bedford - Cape Flattery dunefield (200 kilometres north of Cairns) which has many Quaternary dune features like those in SWBTA. These sinkholes may be linked to offshore freshwater springs emanating from the sea bed. In northern Queensland appearances of such ‘springs in the sea’ are called ‘wonky holes’.

Clear water in the base of a sinkhole, Dismal Sector
SOILS

Soils are formed by natural processes such as weathering of parent rocks, erosion, deposition, and accumulation of organic matter. Large variations in topography, climate, geology and vegetation across SWBTA result in a complex assemblage and distribution of soils (Gunn 1972). The only available mapping of soils in SWBTA was compiled at a scale of 1:2 000 000 and some distribution detail is not available (Northcote et al 1960–68), however detailed soil descriptions were compiled as part of land systems mapping (Gunn 1972).

SWBTA soils are mostly infertile and unstructured, and sub-soils often saline and impervious to water (Tunstall 1993). Most of the surface soils are sandy in nature. Their large particle size and poor structure limits erosion naturally, but the subsoils are often highly erodible especially where salinity levels are high. Gully erosion of subsoils in the Area is limited by the protective effect of the surface soils (Tunstall 1993). These characteristics greatly influence distribution and structure of vegetation communities, and the ability of landscapes to withstand both natural and human impacts.

A soil profile is a vertical section of soil like that shown in the diagram above. Soil profiles assist the examination and description of soil structure. A soil profile is divided into layers called horizons. Beginning at the soil surface, the major soil horizons are A, B, C and D.

The A horizon is sometimes called topsoil. This horizon contains the most life, and together with the B horizon, is most important for plant growth. Depending on the soil, the A horizon is often further divided into A1, A2 and AO (organic). Clays and minerals are washed down (leached) from the A horizon and accumulate in the B horizon, which is known as subsoil.

The C horizon is made up of weathering rock.

At the bottom of the profile is the D horizon which consists of bedrock. This is the rock that has weathered to produce the soil above it, unless the soil has been deposited from elsewhere such as occurs on floodplains.
Soils on the mountain ranges and the southern hills of the Wandilla Formation in SWBTA are mostly skeletal, although derived from various sources (Figure 4.6). These soils are shallow sands and silts with high gravel content. Soils developed over the Shoalwater Formation consist of coarse sand and gravel up to five metres in depth. On other formations they are mostly less than one metre deep and of fine texture. Leached sands and red earths of the western plains are derived from granite and overlay a hard, impervious silica hardpan. Duplex soils with variable definition of the surface layer (A horizon) and subsoil (B horizon) occur to the north and south of these western plains (Figure 4.6). The term duplex describes a soil where there is a sharp texture contrast between the A and B horizons. Duplex soils are often characterised by a sandy or loamy A horizon with a sharp boundary and texture contrast to a clay B horizon. These duplex soils in SWBTA mostly comprise hard-setting loamy surface soils over mottled yellow clayey subsoils.
Both the leached sands over silica hardpan and the duplex soils in western areas (Figure 4.6) restrict Defence training activities during wet periods. Their surface soils have poor structural properties, turning to powder under heavy traffic in dry conditions and turning to an almost fluid state (thixotropic) when wet (Tunstall 1993). Impermeable clay subsoils retain water, making them untraff icable after only moderate rainfall. Furthermore, the subsurface clays in these soils readily disperse when wet and are highly erodible (Tunstall 1993) consequently retention of surface horizons is critical for erosion control and water quality.

The wetter, eastern parts of SWBTA have both sandy loams over heavy clays and podzols on the older sand dunes (Tunstall 1993). Sandy loams mostly have shallow, sandy A horizons of about 20 centimetres deep, with clay subsoils often over lateritic hardpans (Figure 4.6). Podzols form where water percolating through the soil profile carries soluble minerals and clay particles down into the B horizon. Weak humic acids remove any carbonates, leaving a bleached grey or white, coarse-textured and acidic A horizon comprised mostly of quartz sand (silica). The B Horizons are brown in colour with high clay content and characterised by the accumulation of compounds of organic matter, aluminium and/or iron (Tunstall 1993).

The soils of younger parabolic dunes and parallel beach ridges are sands without a podzol profile, because they are constantly being re-worked. Sand dune areas contain numerous freshwater wetlands, totalling over 1 000 hectares. Soils in these areas vary from sand with high organic content to peat layers over one metre thick. The larger wetlands such as Dismal Swamp, Freshwater Swamp, Clinton Low Lands and those in the north-west parts of Townshend Island all contain well developed peat deposits (Jaensch 2008). These deposits are of special scientific interest because of their potential fossil record, distinctive flora and fauna, and carbon sink properties.
Marine clays cover extensive areas in SWBTA (Figure 4.6). These marine sediments are deep, uniform, medium to heavy clays, mostly with a high organic content (Tunstall 1993).

Acid sulfate soils occur in coastal parts of SWBTA (Ross 2000). Testing at 12 sites indicate that soils in coastal areas of SWBTA exceed the acid sulfate soils action criteria and would require remediation if disturbed (Ahern et al 1998). All sites tested showed some acid sulfate development in at least part of the soil profile (Table 4.2; Figure 4.6).

Acid sulfate soils generally occur in waterlogged environments and remain in a largely benign state unless disturbed (NRM&E 2004). Major environmental issues have resulted from drainage of coastal wetlands for agriculture and urban development, but severe localised effects can occur from even limited development such as road construction (Sammut 2000).

There is no large development such as building construction, land clearing or draining in any known areas of SWBTA potentially containing acid sulfate soils. Defence is aware of the potential hazards of disturbing these areas, and management of the issue is embedded in all construction works proposals. Small boat ramps were built at five intertidal sites across the Area, but construction consisted of placing gravel on top of the soil rather than draining or excavating. No acid sulfate soil issues have been observed at any of these sites.

Deeper wheel ruts have the potential to expose acid sulfate soils and vehicle tracks are present across salt marsh at a small number of sites east of Sabina Point. These tracks possibly pre-date Defence ownership of SWBTA, and Standing Orders now specifically prohibit the use of vehicles in coastal wetlands. Vehicular access to salt marshes is also discussed in Chapter 7 in relation to protection of salt marsh vegetation.

The significant biological diversity that exists within SWBTA is largely the product of a complex geological history, diverse soil landscape and variable climatic conditions. The soils are generally erodible but protected by natural vegetation cover. They remain a managed risk for Defence. Fire also plays a role in soil stability and is discussed further in later chapters.

In April 2006, an investigation to determine if any sites across the Area required soil erosion remediation works was undertaken (GHD 2006). Disturbed areas likely to impact on waterways were targeted, including closed landfill sites, roads and tracks, quarries, borrow pits, gravel scapes and old homestead sites. It was concluded that while there was no large scale landscape degradation across the Area actively impacting on waterways, 23 sites required minor remediation works. Remediation of these sites is being progressively addressed as part of annual works programs.
TABLE 4.2
Summary of results for acid sulfate soils testing in SWBTA
(refer Figure 4.6 for location of sites) source: Ross 2000

<table>
<thead>
<tr>
<th>Site No</th>
<th>Depth (m)</th>
<th>AMG Reference</th>
<th>Locality</th>
<th>Landform element *</th>
<th>Acid sulfate hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>CQA219</td>
<td>0.3–0.5</td>
<td>214237mE</td>
<td>7520048mN</td>
<td>Supratidal flat</td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td>1.3–1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQA220</td>
<td>0.3–0.5</td>
<td>214352mE</td>
<td>7519108mN</td>
<td>Tidal creek</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>1.3–1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQA221</td>
<td>1.25–1.5</td>
<td>224603mE</td>
<td>7516024mN</td>
<td>Extratidal flat</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>1.8–2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3–2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQA222</td>
<td>0.2–0.35</td>
<td>224728mE</td>
<td>7516434mN</td>
<td>Tidal creek</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>0.8–1.0</td>
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<td>1.5–1.7</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CQA223</td>
<td>1.3–1.5</td>
<td>241293mE</td>
<td>7501249mN</td>
<td>Intertidal flat</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>1.8–2.0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQA224</td>
<td>0.3–0.5</td>
<td>240994mE</td>
<td>7500261mN</td>
<td>Supratidal flat</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>0.8–1.0</td>
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<tr>
<td></td>
<td>1.3–2.5</td>
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<td></td>
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</tr>
<tr>
<td>CQA225</td>
<td>0.8–1.0</td>
<td>248604mE</td>
<td>7495821mN</td>
<td>Tidal creek</td>
<td>Moderate</td>
</tr>
<tr>
<td>CQA226</td>
<td>1.5–1.7</td>
<td>248560mE</td>
<td>7495870mN</td>
<td>Extratidal flat</td>
<td>High</td>
</tr>
<tr>
<td>CQA227</td>
<td>0.2–0.5</td>
<td>257496mE</td>
<td>7491443mN</td>
<td>Intertidal flat</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>1.2–1.4</td>
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<td></td>
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<tr>
<td>CQA228</td>
<td>0.0–0.15</td>
<td>266898mE</td>
<td>7493988mN</td>
<td>Intertidal flat</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>0.3–1.5</td>
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</tr>
<tr>
<td>CQA229</td>
<td>0.7–0.9</td>
<td>266859mE</td>
<td>7493870mN</td>
<td>Intertidal flat</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>1.2–1.3</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQA230</td>
<td>0.8–1.0</td>
<td>269815mE</td>
<td>7494661mN</td>
<td>Plain</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>1.4–1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The landform element sequence: Tidal creek – Intertidal flat – Supratidal flat – Extratidal flat – Plain, reflects frequency of tidal inundation ranging from daily to very infrequently. See Ross (2000) for further explanation.
Acid sulfate soils are so named because they contain iron sulfides, which when exposed to air oxidise to produce sulfuric acid. A tonne of acid sulfate soil can produce up to one and a half tonnes of sulfuric acid (Sammut 2000). Acid destroys the soil structure and releases toxic quantities of aluminium and other metals, which remain in the soil until leached out by rainfall. Heavy rains following droughts release the most acid and metals, causing massive fish kills. Other organisms such as crustaceans and plants that are unable to escape the acidic waters are often also affected. Acid release can be very destructive of infrastructure materials such as concrete and steel.

Iron sulfide layers in these soils were formed by bacteria in coastal sediments within the last 10,000 years. Bacteria converted iron in land sediments and sulfate from tidal waters into iron sulfides. The iron sulfides are contained in a layer of waterlogged soil, which may be clay, loam or sand (Sammut 2000). Such layers are commonly known as potential acid sulfate soil because of their potential to oxidise to form sulfuric acid. After exposure to air and subsequently producing sulfuric acid they are known as actual acid sulfate soils.

Acid sulfate soils occur naturally over extensive low-lying coastal areas of Australia. These soils are continually being formed under mangrove forests, salt marshes and estuaries, and generally occur in areas less than five metres above mean sea level. They are often present close to the soil surface but may also be found deeper in the soil profile (Sammut 2000). In natural situations, iron sulfide layers exist below the water table, and any acid produced is usually neutralised by alkaline sea water (Sammut 2000).

Exposed acid sulfate soils have the potential to release acid for centuries (Sammut 2000). Therefore, great care must be exercised not to disturb or drain areas where acid sulfate soils occur.
The coastal dunes and headland in The Three Rivers area at the northern end of Five Rocks Beach has been identified as a priority site for erosion control. This area has become highly eroded from the illegal use of quad bikes and four-wheel drive vehicles, with some erosion scars up to three metres deep migrating into the fragile heath vegetation. Illegal camping also occurs in this area, and impacts such as loss of ground cover, presence of rubbish and tree damage are prevalent. At a number of places there is a danger that loss of dune vegetation will lead to increased mobility of sand and subsequent damage to the parabolic dune system.

RECOMMENDATIONS

The following recommendations are made in relation to the geology and soils of SWBTA:

1. Investigate the age and geological relationship of volcanic rocks within SWBTA. There is current debate as to whether they are an extension of the famous Cretaceous Whitsunday Province (100 million years old) or are related to the Triassic Agnes Water Volcanic Province. Further study will remove current uncertainty over the origins of these rocks.

2. Investigate the formative and sustaining factors surrounding the sinkhole features in the eastern sand dunes. A study of these features, including the underlying hydrology and geology, should be undertaken to determine their significance. These investigations would include using geophysical techniques and field and office studies to determine the spatial patterns and details of topographic form.

3. Continue management actions to prevent soil erosion and support further acid sulfate soils sampling and mapping in SWBTA. Defence management of human activities has safeguarded natural soil condition and water quality in the Area. These management actions should continue. Further acid sulphate soils sampling and mapping could be undertaken to confirm their full extent.

4. Investigate the significance of Quaternary sand landforms in the SWBTA. This would involve a combined geomorphological and soils study, with a strong focus on dune morphometry and age dating of dune activity. Based on aerial photos, satellite and other available remote sensing, drilling sites would be selected to establish soil profiles and to obtain samples for age dating. The Clinton Low Lands would be included in this program to resolve the current debate about the age range of the beach ridges. The research would reveal the main SWBTA features and any similarity of these with other areas of Quaternary sand deposition.
ABARE—see Australian Bureau of Agricultural and Resource Economics
Ahern, CR, Ahern, MR & Powell, B 1998, Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland, QASSIT, Department of Natural Resources (Qld), Indooroopilly.


BOM—see Bureau of Meteorology


DCC—see Department of Climate Change


DME—Department of Mines and Energy

EPA—see Environmental Protection Agency


GHD—see Gutteridge, Haskins and Davey Pty Ltd


NRM&E—see Department of Natural Resources, Mines and Energy


Ross, DJ 2000, Acid sulfate soils, Tannum Sands to St Lawrence, Central Queensland Coast, Department of Natural Resources and Mines (Qld), Rockhampton.


