Coastal acid sulfate soil processes in Barker Inlet, South Australia

Doctor of Philosophy

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APPENDIX B

1. Catalogue of Soil Morphology, properties and classification

In Chapter 5 (St Kilda study site) and Chapter 6 (Gillman study site), soil morphological descriptions were provide for selected 'type' soil profiles only.

This Appendix provides descriptions of all soil profiles discussed and referred to throughout the thesis and all 'type' profiles discussed in Chapter 5 (St Kilda study site) and Chapter 6 (Gillman study site). The soil chemical data (including ABA data) that was used to classify the materials and soil profiles is also included.

Morphological descriptions were done on all soil materials sampled, following the conventions of the USDA Field book for describing and sampling soils (Schoeneberger *et al.* 2002), and Australian Soil and Land Survey Field Handbook (McDonald *et al.* 1990). Soil properties such as colour, consistency, structure, porosity, texture, organic matter type and content, redoximorphic features and carbonate content are very useful when interpreting acid sulfate soil conditions.

Pedogenic soil layers (horizons) were denoted notation (e.g. A, B or C) indicating their position in the soil profile and numerical notations to denote special features ((Schoeneberger *et al.* 2002). Soil colour was determined on moist samples using Munsell Soil colour notation (Munsell 1994).

Acid base accounting and soil analytical results were used to classify acid sulfate soil materials according to the classification scheme proposed by Sullivan *et al.* (2010); refer to Table 1-1.

Analytical results (EC, pH_f, pH_W, pH_{OX}, $pH_{Incubation}$, Total S%, Organic C%, $CaCO_3$% and Acid Base Accounting using the S_{CR} suite) for all samples analysed

are provided as graphs in this Appendix. Tables of soil chemical data are provided in Appendix C. Coordinates for soil profile locations are also provided in Appendix C.0

Table 1-1 Acid sulfate soil materials have been classified using the following definitions.

Descriptive terminology	**Definition**
Sulfuric materials	soil materials with a pHw < 4 as a result of sulfide oxidation
*Sulfidic materials	soil materials containing detectable sulfide minerals (≥ 0.01% reduced inorganic S)
Hypersulfidic materials	sulfidic material that has a field pH of 4 or more and experiences a drop in pH by ≥ 0.5 units to 4 or less after ≥8 weeks of incubation
Hyposulfidic materials	sulfidic material that has a field pH ≥ 4 and does not experience a drop in pH by ≥ 0.5 units to 4 or less after ≥ 8 weeks of incubation
Monosulfidic materials	soil materials with an acid volatile sulfur content of 0.01%S or more

**This term differs from previously published definitions in various soil classifications (e.g. Isbell (2002)).*

1.1. Soil morphology and acid sulfate soil characterisation of the St Kilda Study Site

Soil profiles located within focus areas that are representative of the map units (Table 1-2 and Figure 1-1).

Table 1-2 Soil profile numbers marked in **red** are 'type' sections that were described in detail in but are included here for completeness. Profile numbers listed in black font are also described in this Appendix. In addition, soil chemical data for these profiles is tabulated in Appendix C.

Soil profile numbers	Focus area	Map unit no.	Landform	Water State, ponding and drainage
Undisturbed intertidal to supratidal areas (St Kilda study sites)				
BSK 5, 8	**A, C**	9 (Water)	Erosional channel - tidal creek channel	Wet, poorly drained
BSK 4, 1, 2, 7; 600 and 2610	**A, B, C**	10 (Mangrove woodlands)	Open flat –intertidal floodplain	Wet, moderately to poorly drained
BSK 6	**C**	11 (Low growing salt marsh plants)	Open flat – intertidal to supratidal zone	Wet, moderately well drained
BSK 3	**B**	12 (Bare chenier ridge; shell-based)	Open mound – intertidal to supratidal floodplain	Wet, very well drained

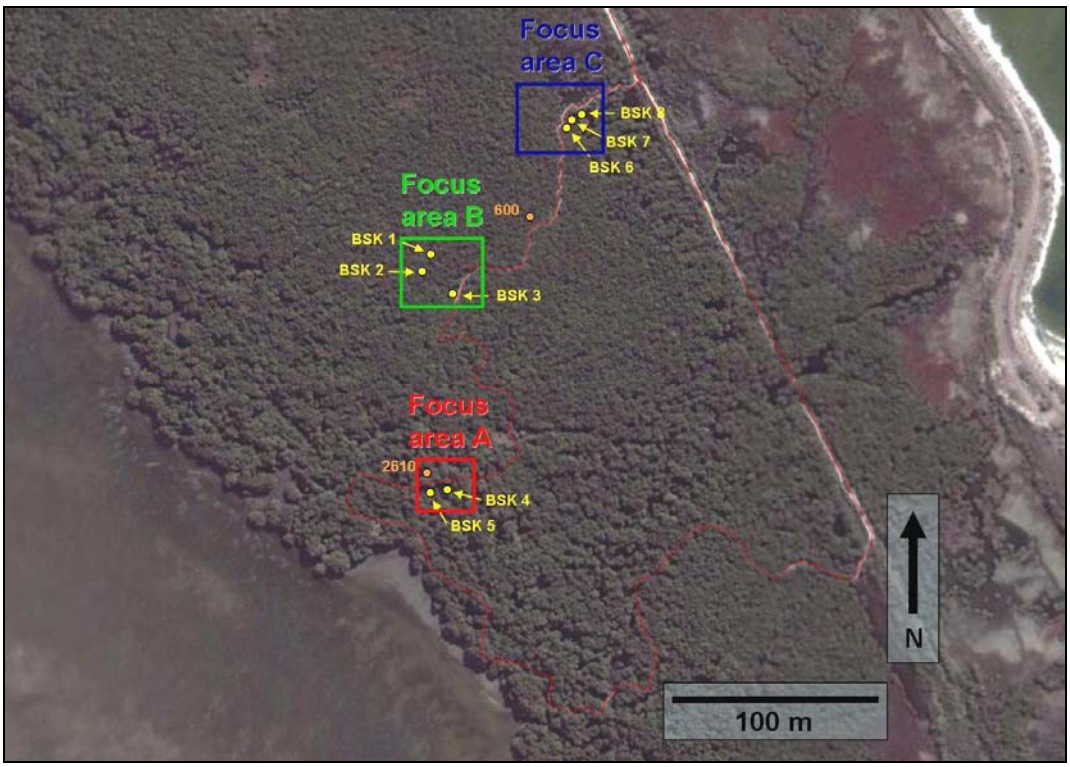


Figure 1-1 St Kilda study site: Focus area – A is located close to the seaward extent of the mangrove woodland and transects a well defined tidal creek. Focus area B – is located on a topographical high and transects from mangrove woodland to a bare patch on the shell based chenier ridge. Focus area – C is located near the upper extent of the intertidal zone and transects samphire marsh, mangrove woodland and permanently inundated tidal creek soils.

1.2. Overview

Associations between map unit and soil types at the St Kilda study site are presented in Table 1-3. The correlations between these mapping units and acid sulfate soil hazards have been explored further in the Chapter 7.

Table 1-3 Map units located within the St Kilda study site (Focus areas A, B and C) combined with soil profiles classified according to Soil Taxonomy (Soil Survey Staff 2010), the Australian Soil Classification (Isbell 2002) and acid sulfate soil terminology (Sullivan *et al.* 2010).

Map unit no. (map unit colour)	Soil profile No	Australian Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid sulfate soil materials
9. Water	BSK 5	Sapric, Histic, Intertidal Hydrosol	Sapric Haplowassists	Hyposulfidic, monosulfidic
	BSK 8	Sapric, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	
10. Mangrove woodlands	BSK 1	Hemic, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	Hyposulfidic, hypersulfidic, monosulfidic
	BSK 4	Sapric, Histic-Sulfidic, Intertidal Hydrosol	Sulfic Haplowassists	
	BSK 7	Hemic, Histic-Sulfidic, Intertidal Hydrosol	Typic Sulfiwassists	
11. Low growing salt marsh plants	BSK 6	Hemic, Histic-Sulfidic, Intertidal Hydrosol	Typic Sulfiwassists	Hypersulfidic
12. Bare chenier ridge (shell-based)	BSK 3	Epicalcareous, Intertidal Hydrosol	Typic Endoaquents	Hyposulfidic

1.3. St Kilda Focus area A with strong tidal influence

Focus area A is situated within mature mangrove woodland, about 50 m from the low tide mark at the seaward fringe of the mangrove forest. This area is close to the exposed seagrass beds of Barker Inlet and has a strong tidal influence (Figure 1-2).

Focus Area A encompasses a toposequence that traverse from relatively high (elevation of about 0.6 m AHD) intertidal floodplain covered by thick mangrove pneumatophore root masses, to lower lying (elevation of about 0.3 m AHD) permanently inundated, eroded tidal creek (Figure 1-3). Two soil profiles (BSK 4 and BSK 5) are located on the toposequence and are representative of map units 10 (Mangrove woodland) and 9 (Water) respectively (Table 1-4).

Table 1-5 provides a summary of the soil taxonomy for soil profiles in St Kilda focus area A.

Table 1-4 Soil profiles selected to be representative of map units occurring within focus area A, located on toposequence transect A-A' in Figure 1-2.

Soil profile numbers	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Intertidal zone				
BSK 5	0.3 m AHD	9 (Water)	Erosional channel - tidal creek channel	Wet
BSK 4	0.6 m AHD	10 (Mangrove woodlands)	Open flat –intertidal floodplain	Wet, moderately to poorly drained

Table 1-5 St Kilda Focus area A soil profiles are classified according to Australian Soil Classification (Isbell 2002), Soil Taxonomy (Soil Survey Staff 2010) and using acid sulfate soil terminology (Sullivan *et al.* 2010).

Soil profile no.	Map unit no.	Aust. Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid Sulfate Soil materials	Significant net acidity occurrence
Intertidal zone					
BSK 4	**10 (Mangrove woodlands)**	Sapric, Histic-Sulfidic, Intertidal Hydrosol	Sulfic Haplowassists	Hyposulfidic, hypersulfidic, monosulfidic	40 cm @ 275 mole H^+/t from 110 cm depth and 0.02% AVS
BSK 5	**9 (Water)**	Sapric, Histic, Intertidal Hydrosol	Sapric Haplowassists	Hyposulfidic, monosulfidic	210 cm @ -531 mole H^+/t from 0 cm depth and 0.02% AVS

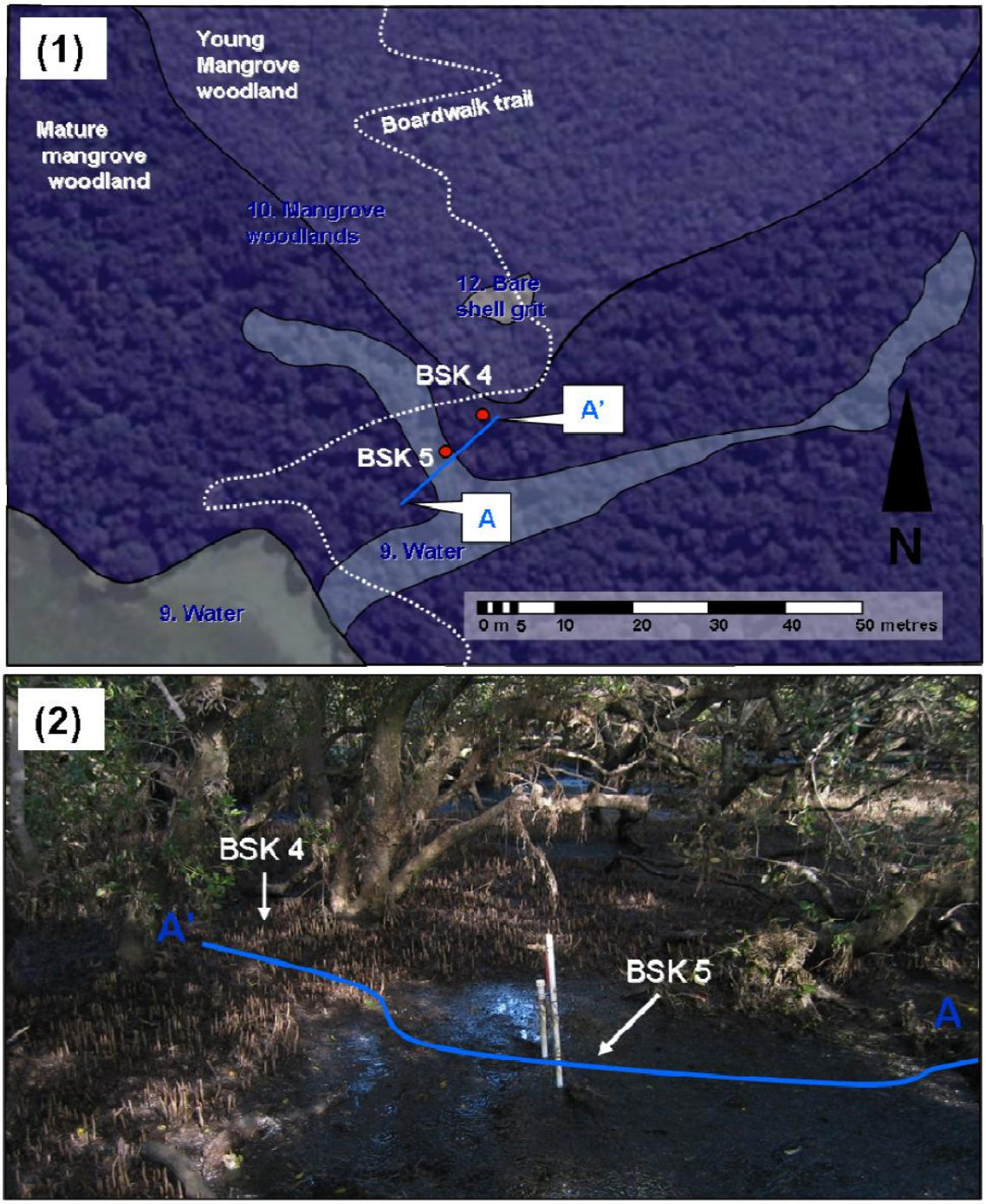


Figure 1-2 Map (1) showing map units in Focus area A and location of toposequence transect A-A' with soil profiles BSK 4 and BSK 5. The St Kilda boardwalk is indicated by the white dotted line. Landscape photo (2) showing the relative positions of soil profiles along the toposequence transect and contrasts between mapping units.

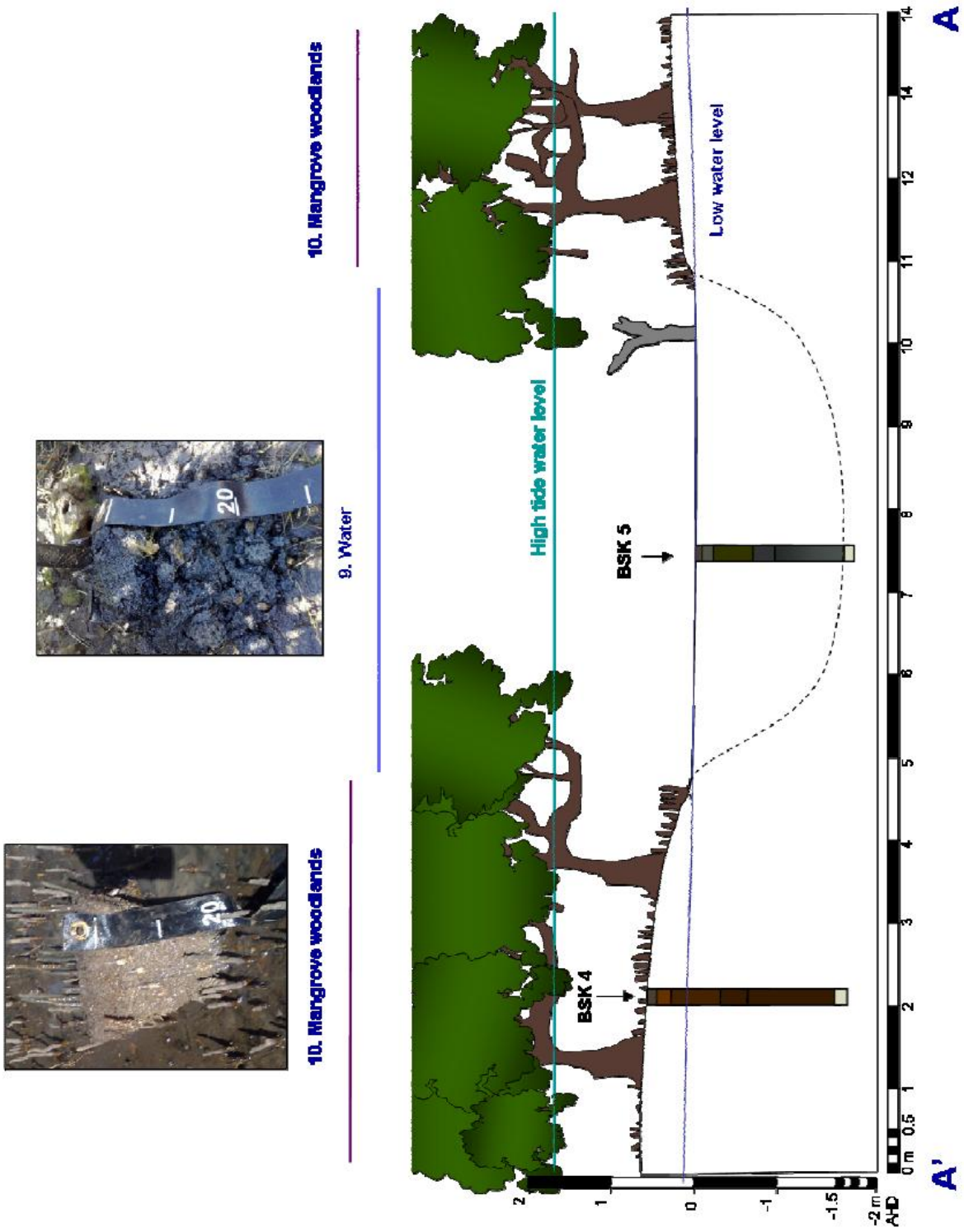
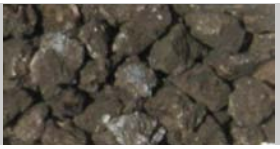


Figure 1-3 Descriptive soil-regolith toposequence model (cross section A-A' as shown Figure 5-3) indicating map units and position of representative soil profiles with colour photograph and average water table depths during low and high tide. The dotted line indicates the shape of the filled tidal creek depression at profile BSK 5. Refer to Table 1-6 and Table 1-7 for soil profile descriptions.

Map unit 10 - *Wet: moderately to poorly drained, open flat intertidal flood plain covered by mangrove woodland. Profile BSK 4* – (Table 1-6 and Figure 1-3).

Table 1-6 Summary of soil morphology for profile BSK 4: *Wet: saturated (permanent), very poorly drained wetland.* Soil colour was determined on moist samples and consistence on dry samples. Photos show dried samples.

Horizon (ID)	Depth	Soil morphology	Sample (5 x 2.5 cm)
Oe/W1 (BSK 4-68)	0-5 cm	Very dark brown (10YR2/2) peat (5% mineral, 95% fibric and hemic material); abundant coarse live roots; diffuse boundary	
Oe/W2 (BSK 4-69)	5-10 cm	Very dark brown (10YR2/2) peat (5% mineral, 95% hemic material); abundant coarse live roots; diffuse boundary	
Oe/W3 (BSK 4-70)	10-20 cm	Very dark brown (10YR2/2) peat (5% mineral, 95% sapric and hemic material); abundant coarse live roots; diffuse boundary	
Oe/W4 (BSK 4-71)	20-50 cm	Black (5Y2.5/1) peat (5% mineral, 95% sapric and hemic material); some coarse live roots; diffuse boundary	
Oe/W5 (BSK 4-72)	50-90 cm	Black (5Y2.5/1) peat (5% mineral, 95% sapric and hemic material); no roots; diffuse boundary	
Oe/W6 (BSK 4-73)	90-110 cm	Very dark brown (10YR2/2) clayey peat (10% mineral, 90% sapric and hemic material); no roots; diffuse boundary	
Oe/W7 (BSK 4-74)	110-130 cm	Very dark brown (10YR2/2) clayey peat (10% mineral, 90% sapric material); no roots; diffuse boundary	
Oe/W8 (BSK 4-75)	130-150 cm	Very dark brown (10YR2/2) clayey peat (10% mineral, 90% sapric material); no roots; diffuse boundary	
Oe/W9 (BSK 4-76)	150-170 cm	Very dark brown (10YR2/2) peaty clay (15% mineral, 85% sapric material); no roots; diffuse boundary	
Oe/W10 (BSK 4-77)	170-190 cm	Very dark grey (10YR3/1) peaty clay (20% mineral, 80% sapric material); no roots; slight H_2S smell; clear wavy boundary	
Oek/W11 (BSK 4-78)	190-210 cm	Grey (10YR5/1) peaty clay (40% mineral, 60% sapric material); no roots; slight H_2S smell; some medium to coarse broken shell fragments.	

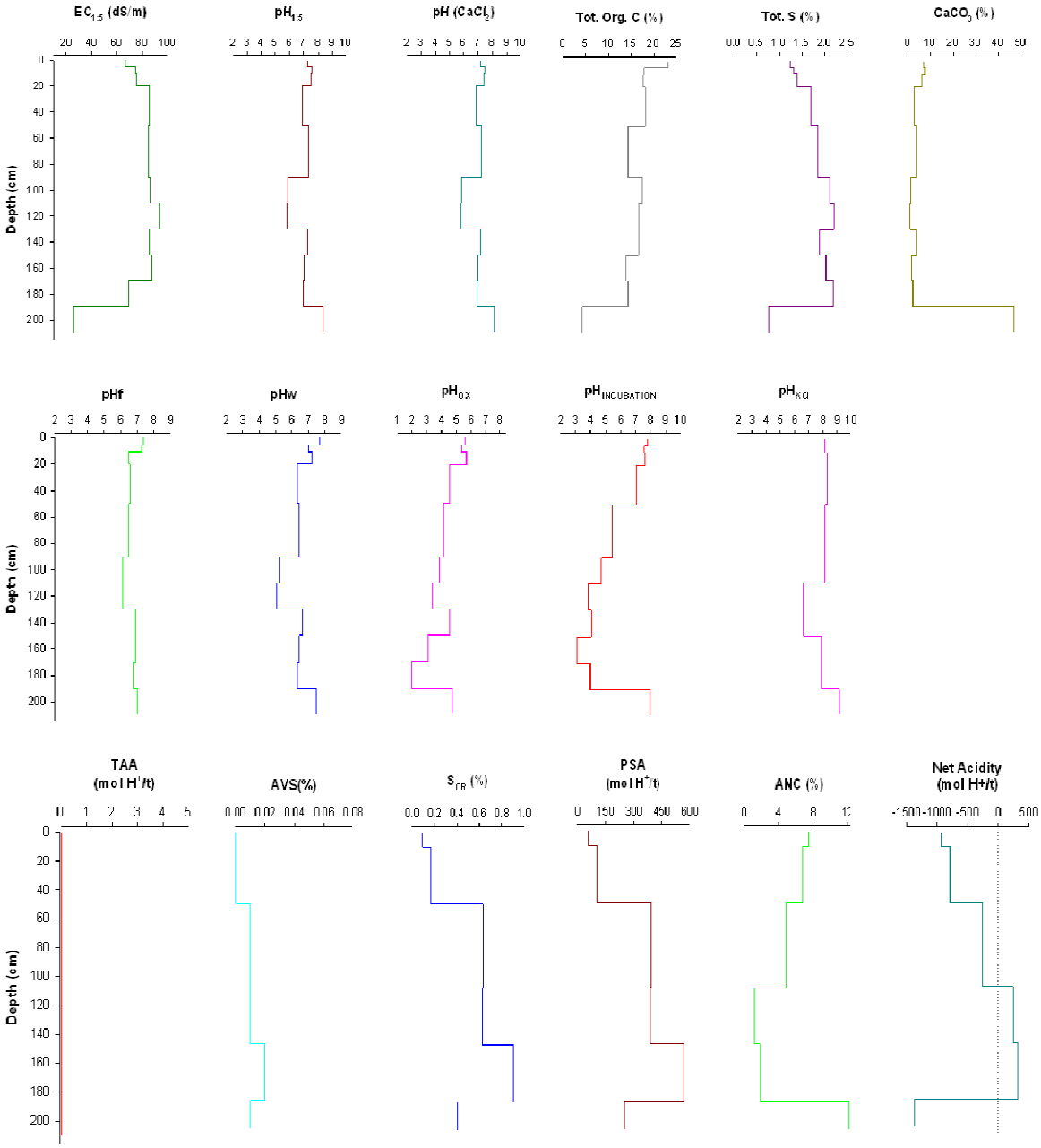


Figure 1-4 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 4. All soils analytical data are tabulated in Appendix C.

Map unit 9 – *Wet: poorly drained, erosional tidal creek depression covered by water. Profile BSK 5* – (Table 1-7 and Figure 1-5)

Table 1-7 Summary of soil morphology for profile BSK 5: *Wet: saturated (permanent), very poorly drained, inner wetland*. Soil colour was determined on moist samples and consistence on dry samples. Photos are of dry samples.

Horizon (ID)	Depth	Soil morphology	Sample (5 x 2.5 cm)
Oe/W1 (BSK 5-79)	0-10 cm	Very dark brown (10YR2/2) peat (2% mineral, 98% fibric, hemic and sapric material); no roots; very diffuse boundary. Thin (<1 mm) white striated slick / mat on water and moist soil surface)	
Oe2/W2 (BSK 5-80)	10-30 cm	Black (5Y2.5/1) peat (<5% mineral, >95% hemic and sapric material); no roots; very diffuse boundary	
Oe/W3 (BSK 5-81)	30-60 cm	Black (5Y2.5/1) peat (5<% mineral, >95% fibric, hemic and sapric material); no roots; diffuse boundary	
Oe/W4 (BSK 5-82)	60-110 cm	Very dark brown (10YR2/2) peat (5% mineral, 95% fibric, hemic and sapric material); no roots; diffuse boundary	
Oe/W5 (BSK 5-83)	110-150 cm	Very dark brown (10YR2/2) peat (5% mineral, 95% sapric and hemic material); no roots; some coarse shell fragments; diffuse boundary	
Oe/W6 (BSK 5-84)	150-190 cm	Very dark brown (10YR2/2) organic rich clay loam (40% mineral, 60% sapric material); no roots; some coarse shell fragments; diffuse boundary	
Oek/W7 (BSK 5-85)	190-210 cm	Grey (10YR5/1) organic rich clay (50% mineral, 50% sapric material); no roots; slight H_2S smell; some medium to coarse broken shell fragments.	

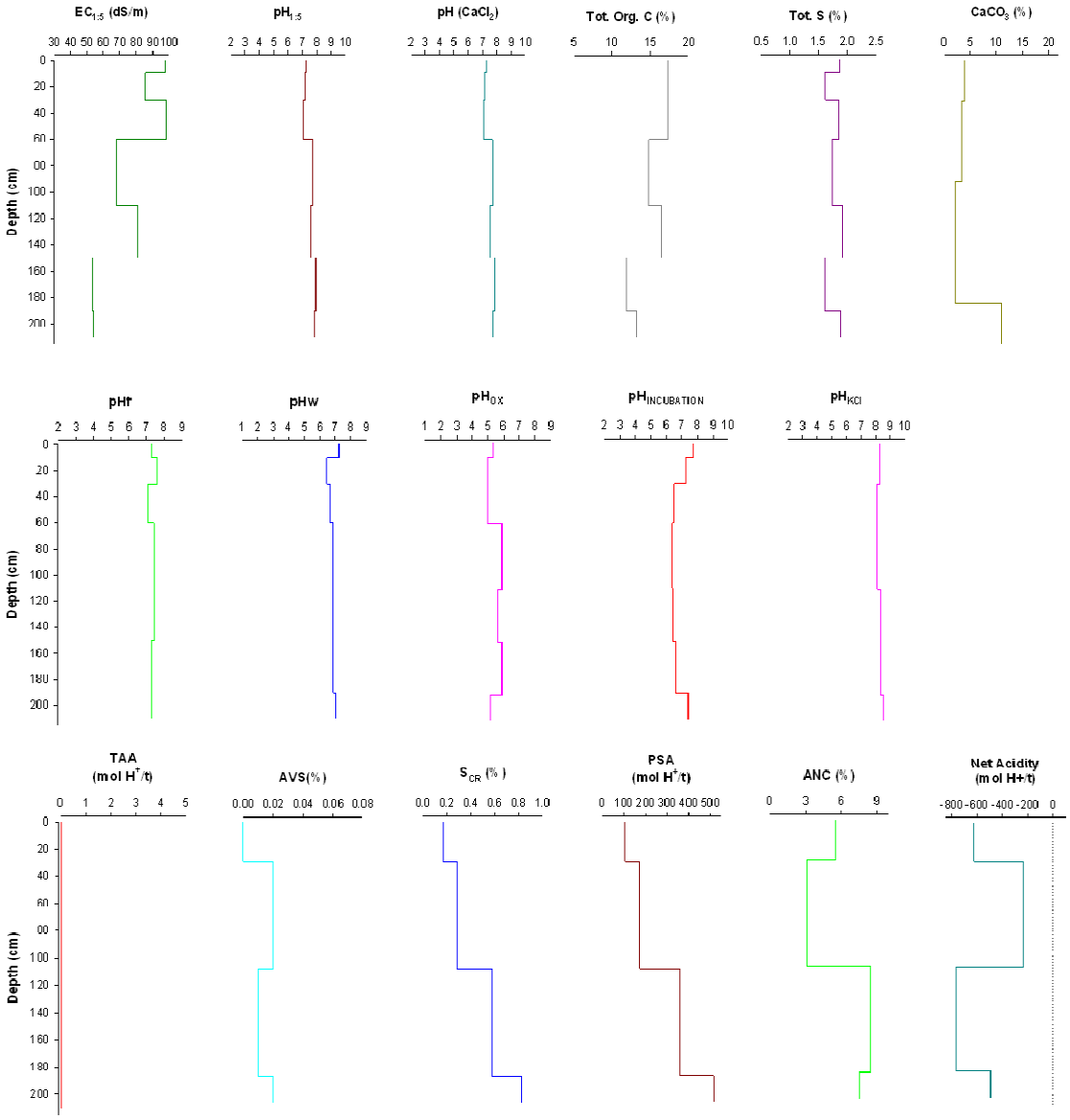


Figure 1-5 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 5. All soils analytical data are tabulated in Appendix C.

1.3.1. St Kilda Focus area B – on an elevated, bare, shell grit chenier ridgeline

Focus area B is situated on a slightly elevated shell grit ridgeline (chenier) that is flanked by mangrove woodlands. This area is about 250 m from the low tide mark (Figure 1-1). Focus area B encompasses a toposequence that transects from a relatively high, bare chenier ridge with an elevation of about 1.3 m AHD, to low-lying intertidal mangrove woodlands with an elevation of about 0.8 m AHD (Table 1-8 and Figure 1-6). Two soil profiles (BSK 1 and BSK 3) are located on the toposequence and are representative of map units 10 (Mangrove woodland) and 12 (Bare chenier ridge) (Table 1-8 and Figure 1-7). Both profiles are inundated during high tide. Table 1-9 provides a summary of the soil taxonomy for these profiles.

Table 1-8 Soil profiles selected to be representative of map units occurring within focus area A, and along toposequence transect B-B' in Figure 1-6.

Soil profile no.	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Intertidal zone				
BSK 1	**0.8 m AHD**	**10 (Mangrove woodlands)**	Open flat –intertidal floodplain	Wet, moderately to poorly drained
BSK 3	**1.3 m AHD**	**12 (Bare chenier ridge; shell-based)**	Open mound –intertidal to supratidal floodplain	Wet, very well drained

Table 1-9 St Kilda Focus area B soil profiles are classified according to Australian Soil Classification (Isbell 2002), Soil Taxonomy (Soil Survey Staff 2010) and using acid sulfate soil terminology (Sullivan *et al.* 2010).

Soil profile no.	Map unit	Aust. Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid Sulfate Soil materials	Significant net acidity occurrence
Intertidal Zone					
BSK 1	**10 (Mangrove woodlands)**	Hemic, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	Hyposulfidic	12 cm @ -234 mole H^+/t from 0 cm depth
BSK 3	**12 (Bare chenier ridge)**	Epicalcareous, Intertidal Hydrosol	Typic Endoaquents	Hyposulfidic	70 cm @ -1610 mole H^+/t from 0 cm

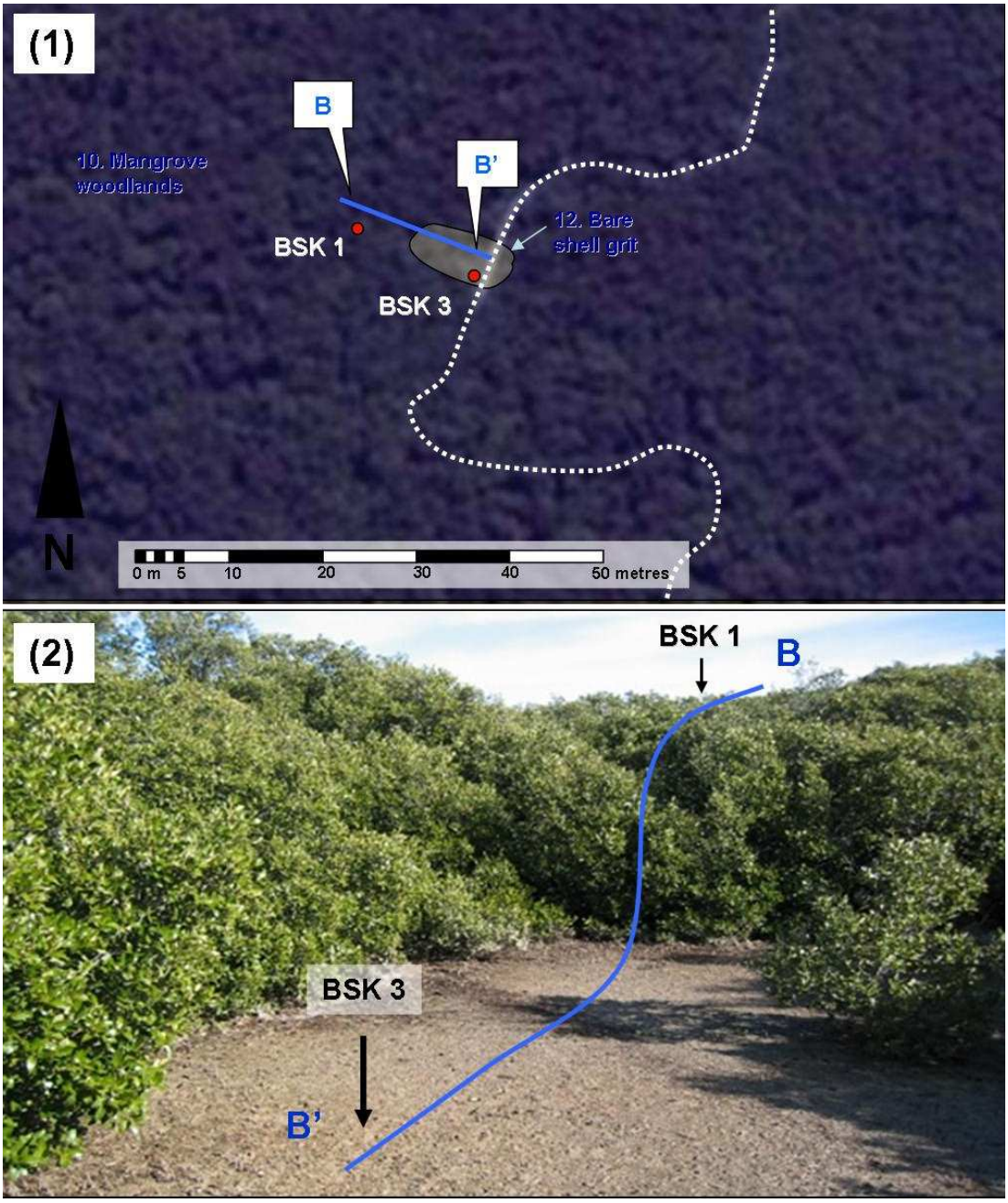


Figure 1-6 Map (1) showing map units in Focus area B and the location of toposequence transect B-B' with soil profiles BSK 1 and BSK 3. The St Kilda boardwalk is indicated by the white dotted line. Landscape photo (2) shows the relative positions of soil profiles along the toposequence transect and contrasts between the mapping units.

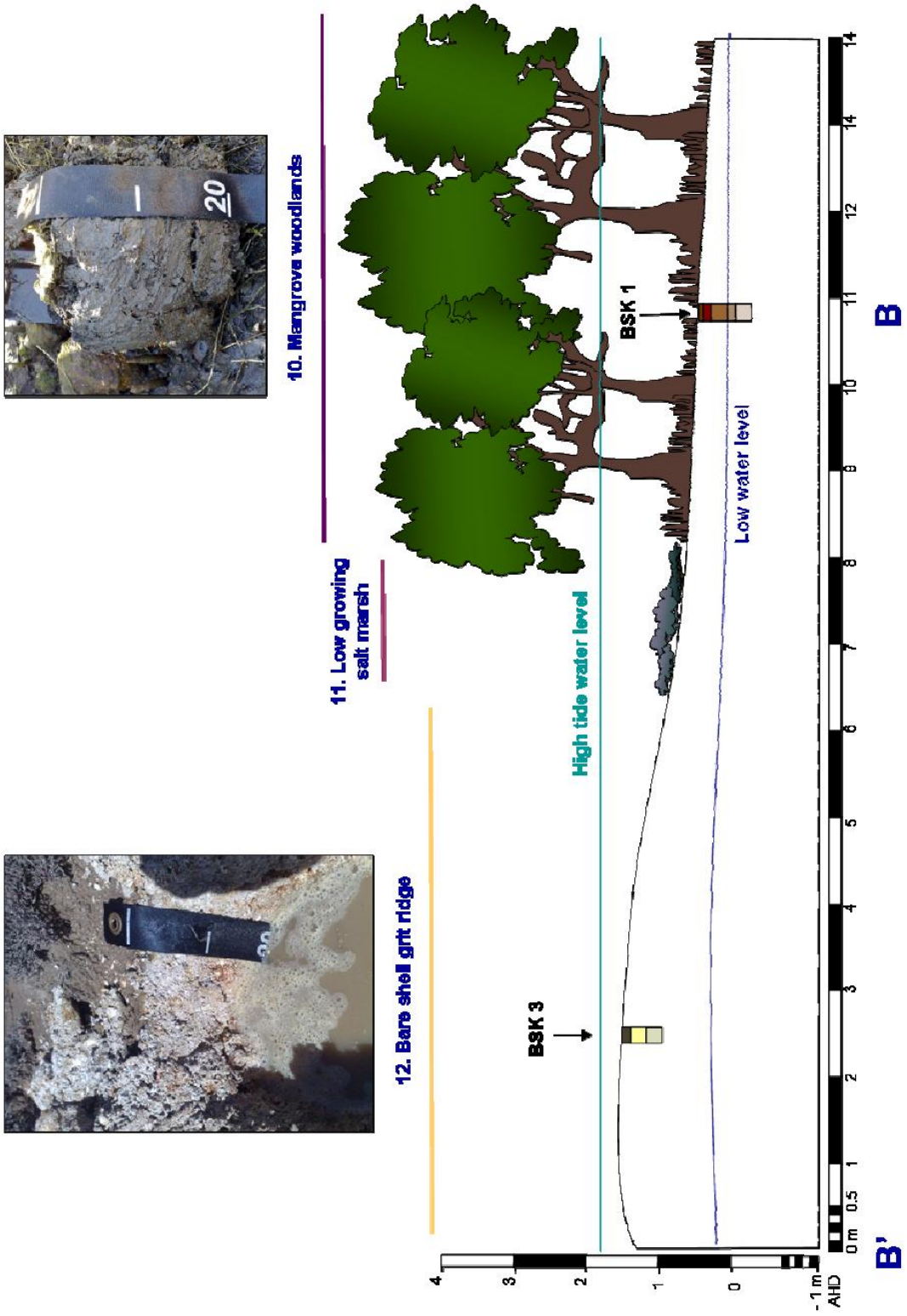


Figure 1-7 Descriptive soil-regolith toposequence model (cross section B-B' as shown in Figure 5-6) indicating map units and position of representative soil profiles with colour photograph and average water table depths during low and high tide.

Map unit 10 - ***Wet: moderately to poorly drained, open flat intertidal flood plain covered by mangrove woodland (mature trees). Profile BSK 1*** – (Table 1-10 and Figure 1-8).

Table 1-10 Summary of soil morphology for profile BSK 1: *Wet: satiated (permanent), very poorly drained, inner wetland.* (Soil colour determined moist and consistence dry).

Horizon (ID)	Depth	Soil morphology	Sample (5 x 2.5 cm)
Oe/W1 (BSK 1-53)	0-12 cm	Very dark brown (10YR2/2) loam (5% mineral, 95% fibric and hemic material); abundant very coarse roots and medium roots; diffuse boundary	
Oe/W2 (BSK 1-54)	12-32 cm	Black (5Y2.5/1) clay loam (5% mineral, 95% hemic material); many very coarse roots and medium roots; gradual wavy boundary	
Oe/W3 (BSK 1-55)	32-48 cm	Very dark grey (10YR3/1) loam (20% mineral, 80% hemic material); common medium and coarse roots; slight H_2S smell; gradual wavy boundary	
Oe/W4 (BSK 1-56)	48-55 cm	Very dark grey (10YR3/1) clay loam (20% mineral, 80% sapric and hemic material); some medium and coarse roots; slight H_2S smell; clear wavy boundary	
B/W5 (BSK 1-57)	55-60 cm	Light grey (10YR7/1) shell hash with coarse broken shell fragments.	

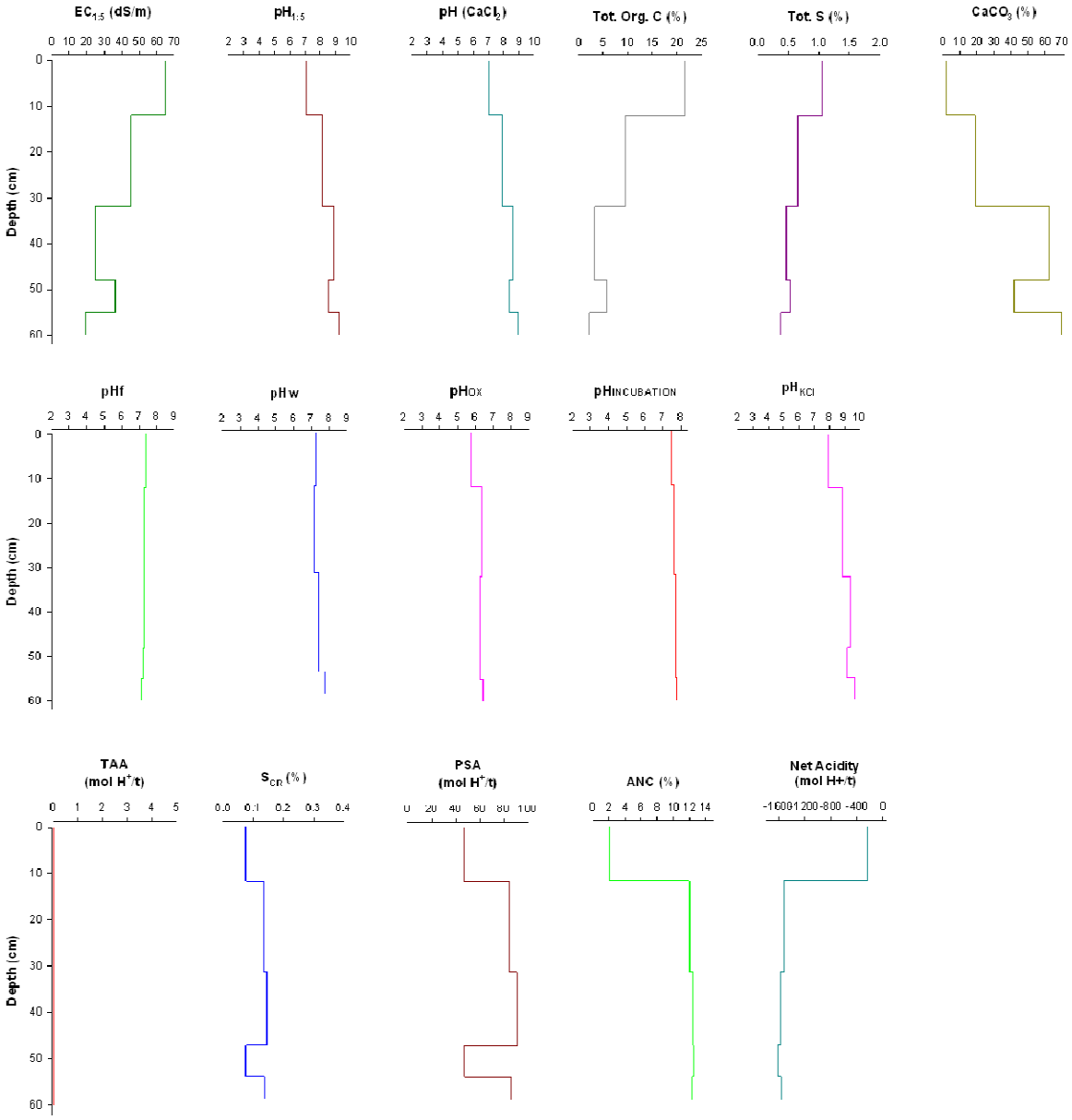


Figure 1-8 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 1.

Map unit 12 - *Wet: very well drained, open mound in an intertidal floodplain covered by a bare, shell-based, chenier ridge. Profile BSK 3* – (Table 1-11 and Figure 1-9)

Table 1-11 Summary of soil morphology for profile BSK 3: *Wet: saturated (permanent), very poorly drained, inner wetland.* Soil colour was determined on moist samples and consistence determined on dry samples. Photos are of dried bulk samples.

Horizon (ID)	Depth	Soil morphology	Sample (5 x 2.5 cm)
Oa1 (BSK3-63)	0-5 cm	Very dark brown (10YR2/2) clay (10% mineral, 50% hemic material); many coarse and medium live roots; material; some coarse carbonate fragments with strong brown coatings (<5% volume); clear smooth, wavy boundary	
Oa2 (BSK3-64)	5-15 cm	Very dark greyish brown (10YR3/2) clay (30% mineral, 70% sapric material); many coarse and medium roots; minor H_2S smell; gradual wavy boundary. Some shell surfaces have strong brown coatings (<5% volume)	
B/W1 (BSK3-65)	15-30 cm	Light grey (10YR7/1) shell hash with some sapric material and some live roots. Minor strong brown (7.5YR 5/8) mottles on shell surfaces (5% volume). Carbonate shell fragments are coarse; diffuse boundary	
B/W2 (BSK3-66)	30-55 cm	While (10YR8/1) shell hash with abundant coarse broken shells. Few strong brown (7.5YR 5/8) mottles on shell surfaces (2% volume). Diffuse boundary	
B/W3 (BSK3-67)	55-70 cm	While (10YR8/1) shell hash with abundant very coarse broken shells.	

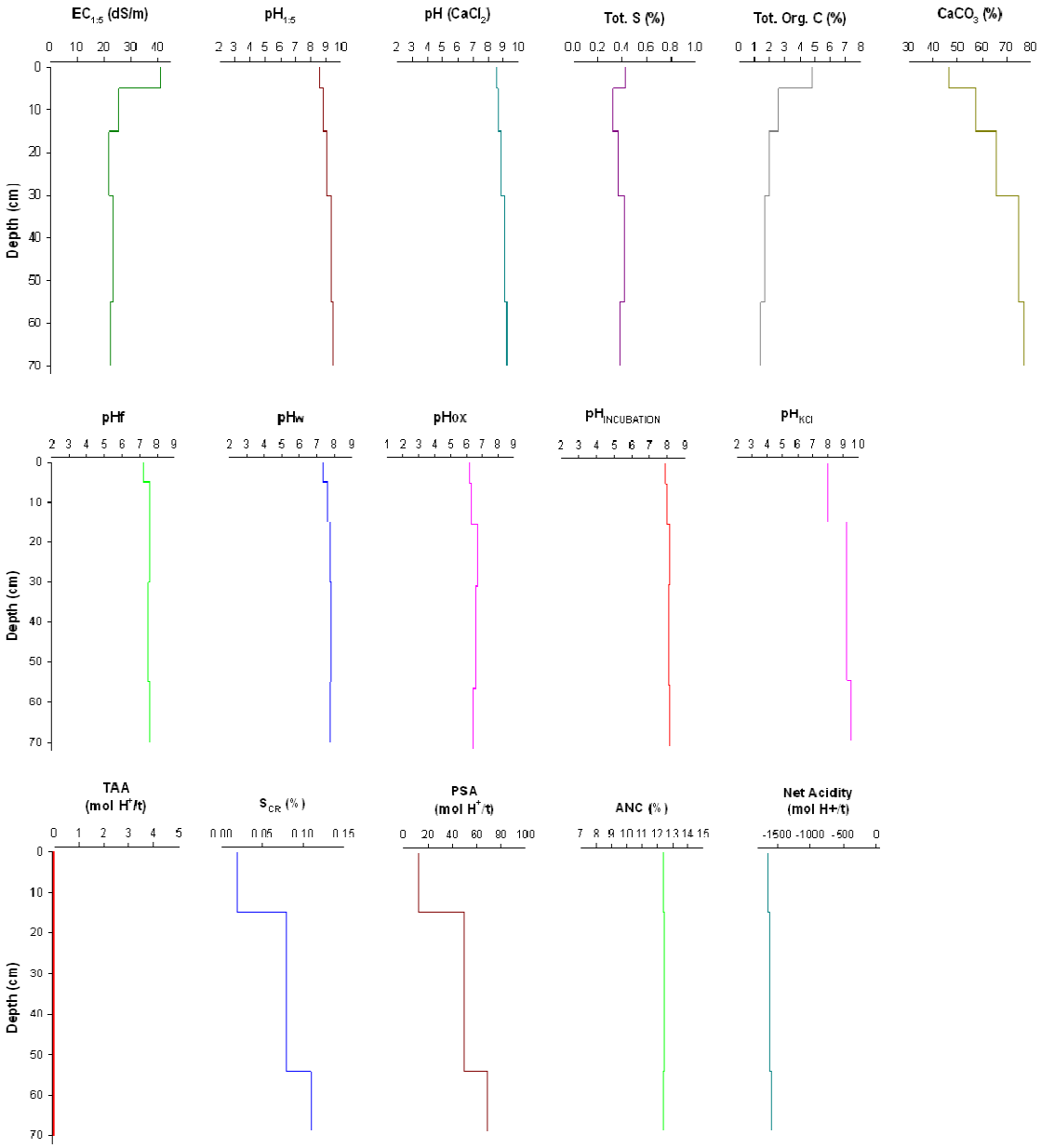


Figure 1-9 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 3.

1.3.2. St Kilda Focus area C comprising a scalped depression with intertidal samphire shrublands and mangrove woodlands

An old bund wall was constructed at St Kilda in the 1890s from scalping nearby intertidal sediments and forms the eastern boundary to the St Kilda study site (Figure 1-1). A permanently inundated depression runs parallel to either side of the bund wall as a relic of its construction. St Kilda Focus area C covers a portion of this modified area (Table 1-12 and Figure 1-10). It encompasses three soil profiles located on a 20 m long northeast trending toposequence that transects across intertidal samphire shrublands, mangrove woodlands and low lying permanently inundated tidal creek channel soils (Figure 1-11). The toposequence crosses the following three map units: **11** (Low growing salt marsh plants), **10** (Mangrove woodlands) and **9** (Water). Table 1-13 provides a summary of soil taxonomy for these profiles.

Table 1-12 Soil profiles selected to be representative of map units occurring within focus area C, and along toposequence transect C-C' in Figure 1-10.

Soil profile numbers	Elevation	Map unit	Landform	Water State, ponding and drainage
Intertidal to supratidal areas				
BSK 6	**1.2 m AHD**	**11.** Low growing salt marsh plants	Open flat – intertidal to supratidal zone	Wet, poorly to moderately well drained
BSK 7	**0.9 m AHD**	**10.** Mangrove woodlands	Open flat –intertidal floodplain	Wet, moderately to poorly drained
BSK 8	**0.0 m AHD**	**9.** Water	Erosional channel - tidal creek channel	Wet, poorly drained

Table 1-13 St Kilda Focus area C soil profiles are classified according to Australian Soil Classification (Isbell 2002), Soil Taxonomy (Soil Survey Staff 2010) and using acid sulfate soil terminology (Sullivan *et al.* 2010).

Soil profile no.	Map unit	Aust. Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid sulfate soil materials	Significant net acidity occurrence
Intertidal Zone					
BSK 6	**11.** Low growing salt marsh plants	Hemic, Histic-Sulfidic, Intertidal Hydrosol	Typic Sulfiwassists	Hyposulfidic, hypersulfidic	30 cm @ 246 mole H^+/t from 0 cm depth
BSK 7	**10.** Mangrove woodlands	Hemic, Histic-Sulfidic, Intertidal Hydrosol	Typic Sulfiwassists	Hyposulfidic, hypersulfidic	30 cm @ 459 mole H^+/t from 0 cm depth
BSK 8	**9** Water	Sapric, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic	15 cm @ 42 mole H^+/t from 10 cm depth and a max 0.18% AVS

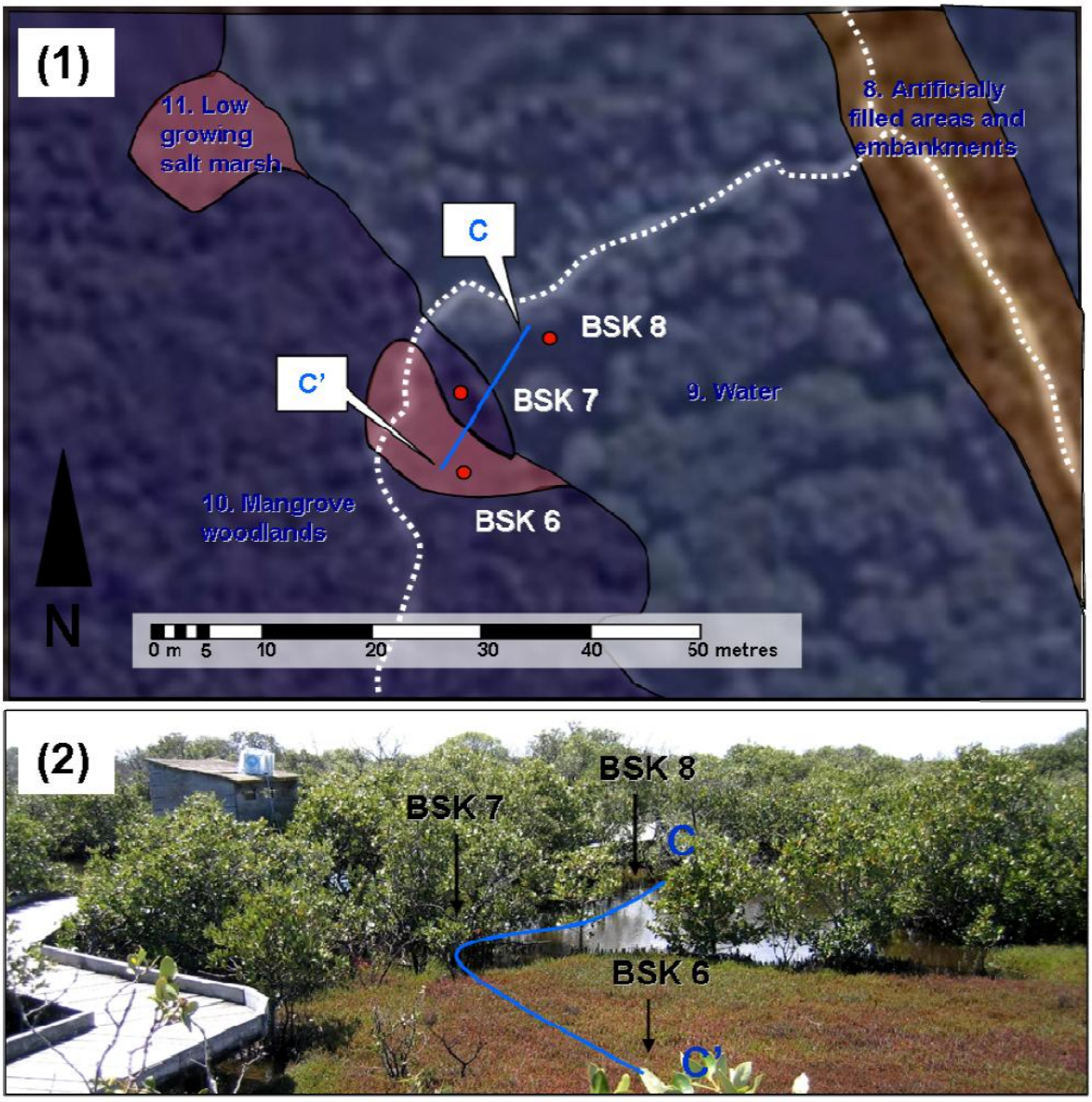


Figure 1-10 (1) Figure showing the map units in Focus area C and the location of toposequence transect C-C' and soil profiles BSK 6, BSK 7 and BSK 8. The St Kilda boardwalk, which also runs along the top of the old bund wall, illustrated as map unit 8 (Artificially filled areas and embankments), is indicated by the white dotted line. **(2)** Landscape photo showing the relative positions of soil profiles along the toposequence transect and contrasts between the map units. A redox data logger was located in the white box on top of the grey wooden bird-hide and recorded soil redox conditions at depth increments within these three soil profiles.

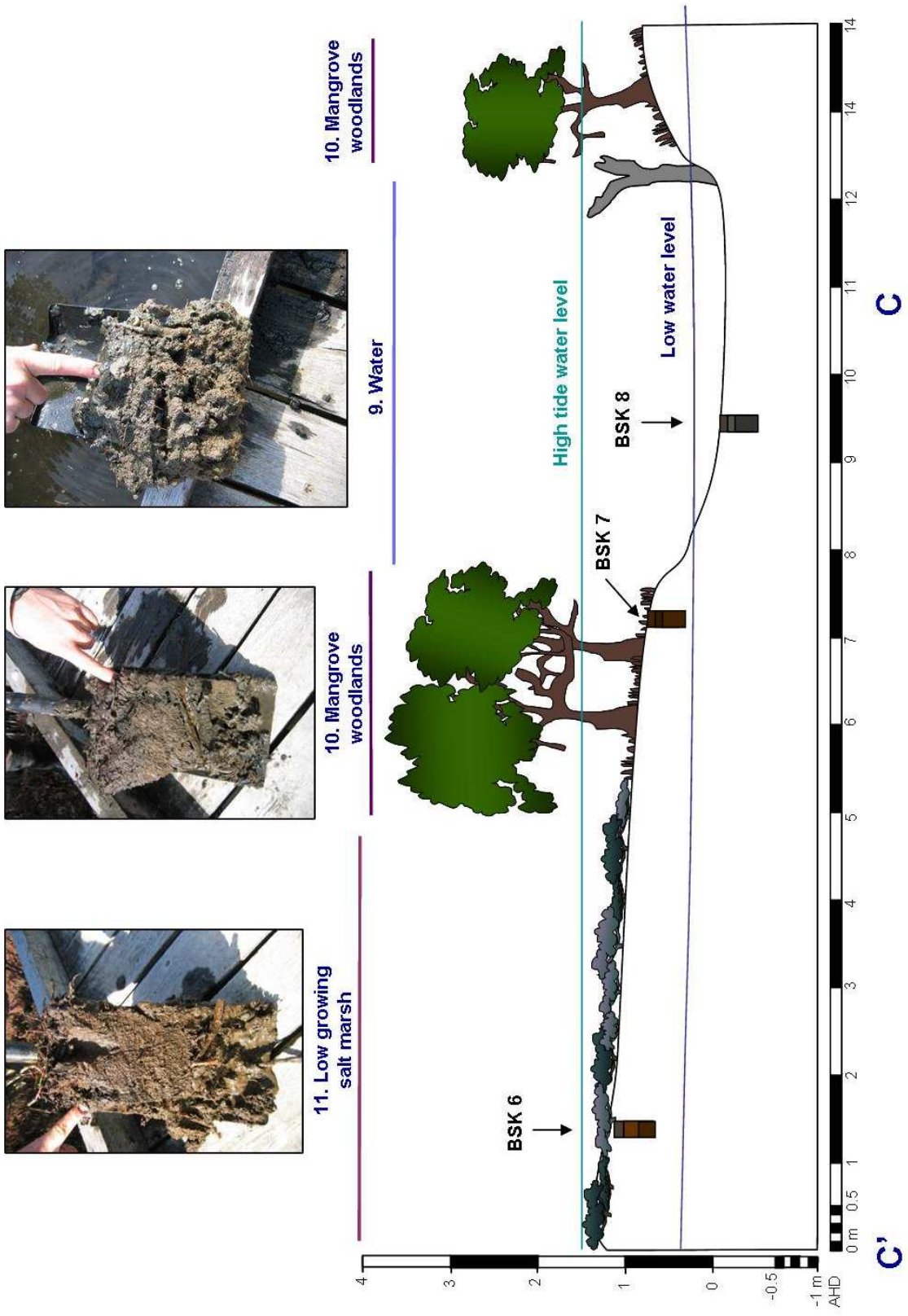


Figure 1-11 Descriptive soil-regolith toposequence model (cross section C-C' as shown in Figure 1-10) indicating map units and position of representative soil profiles with colour photograph and average water table depths during low and high tide.

Map unit 11 – *Wet: poorly to moderately well drained, open flat intertidal floodplain covered by low growing salt marsh plants plants. Profile BSK 6* – (Table 1-14 and Figure 1-12)

Table 1-14 Summary of soil morphology for profile BSK 6: *Wet: satiated (subaqueous), poorly drained, intertidal wetland.* Soil colour was determined on moist samples and consistence on dry samples. Photos shown here are of wet samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Oe/W1 (BSK 6-86)	0-5 cm	Very dark brown (10YR2/2) clayey peat (5% mineral, 95% fibric and hemic material); abundant coarse and medium live roots; minor strong brown (7.5YR5/8) mottles coating live root channels (<5% volume); diffuse boundary	
Oe/W2 (BSK 6-87)	5-15 cm	Very dark brown (10YR2/2) clayey peat (10% mineral, 90% fibric and hemic material); abundant coarse and medium live roots; few strong brown (7.5YR5/8) mottles coating live root channels (<2% volume); gradual wavy boundary	
Oe/W3 (BSK 6-88)	15-30 cm	Very dark grey brown (10YR2/3) peaty clay (20% mineral, 80% hemic material); many medium live roots; slight H_2S smell.	

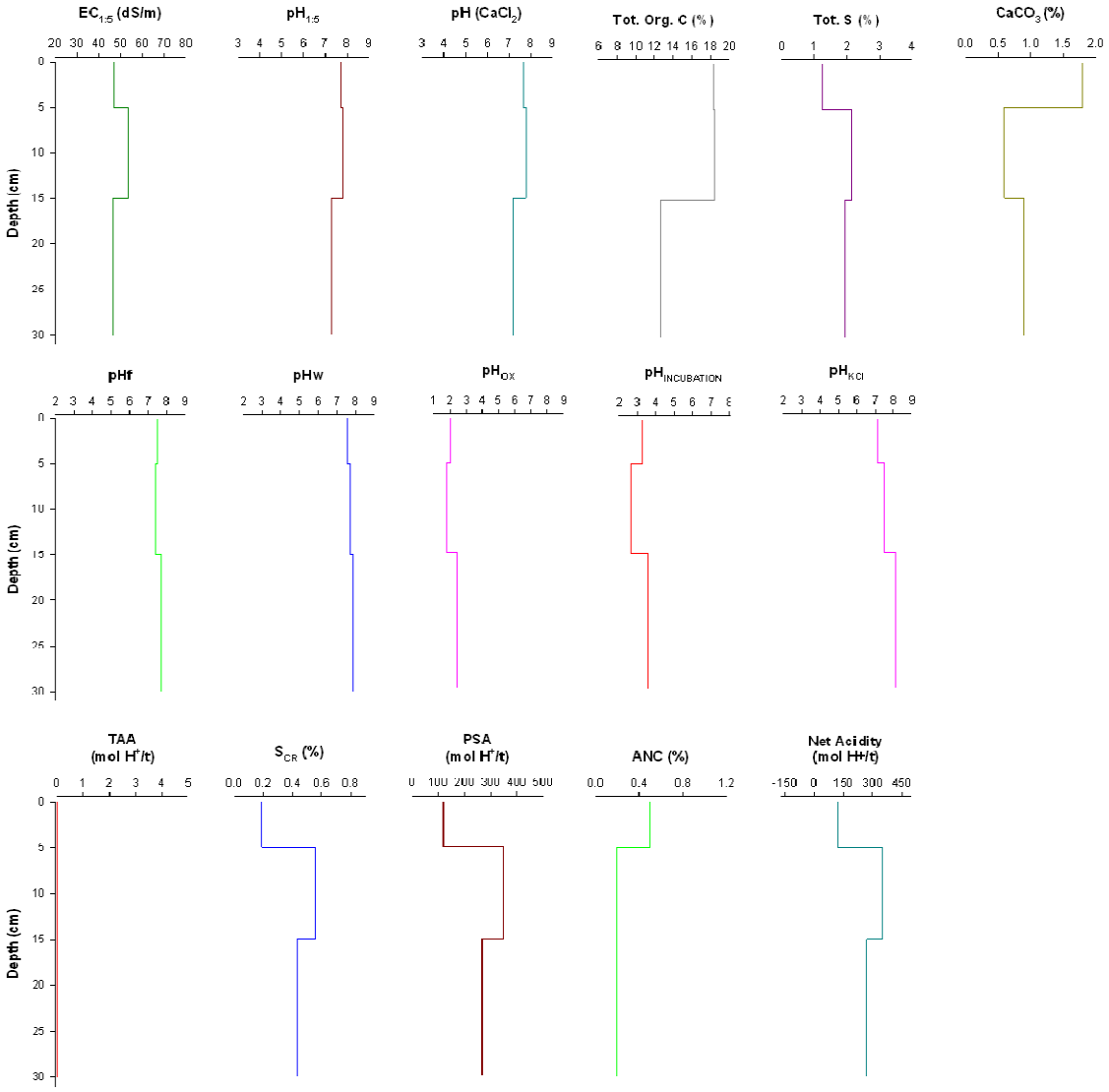


Figure 1-12 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 6.

Map unit 10 - ***Wet: moderately to poorly drained, open flat intertidal flood plain covered by mangrove woodland (mature trees). Profile BSK 7 –*** (Table 1-15and Figure 1-13)

Table 1-15 Summary of soil morphology for profile BSK 7: *Wet: satiated, poorly drained, intertidal wetland*. (Soil colour determined moist and consistence dry).

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Oe/W1 (BSK 7-89)	0-5 cm	Very dark brown (10YR2/2) organic clay (5% mineral, 95% fibric and hemic material); abundant coarse and medium live roots with a slight strong brown (7.5YR5/8) staining (<2%volume); diffuse boundary	
Oe/W2 (BSK 7-90)	5-15 cm	Very dark brown (10YR2/2) organic clay (10% mineral, 90% fibric and hemic material); abundant coarse and medium live roots; gradual wavy boundary	
Oe/W3 (BSK 7-91)	15-30 cm	Very dark grey brown (10YR2/3) clay (20% mineral, 80% hemic material); many medium live roots; slight H_2S smell.	

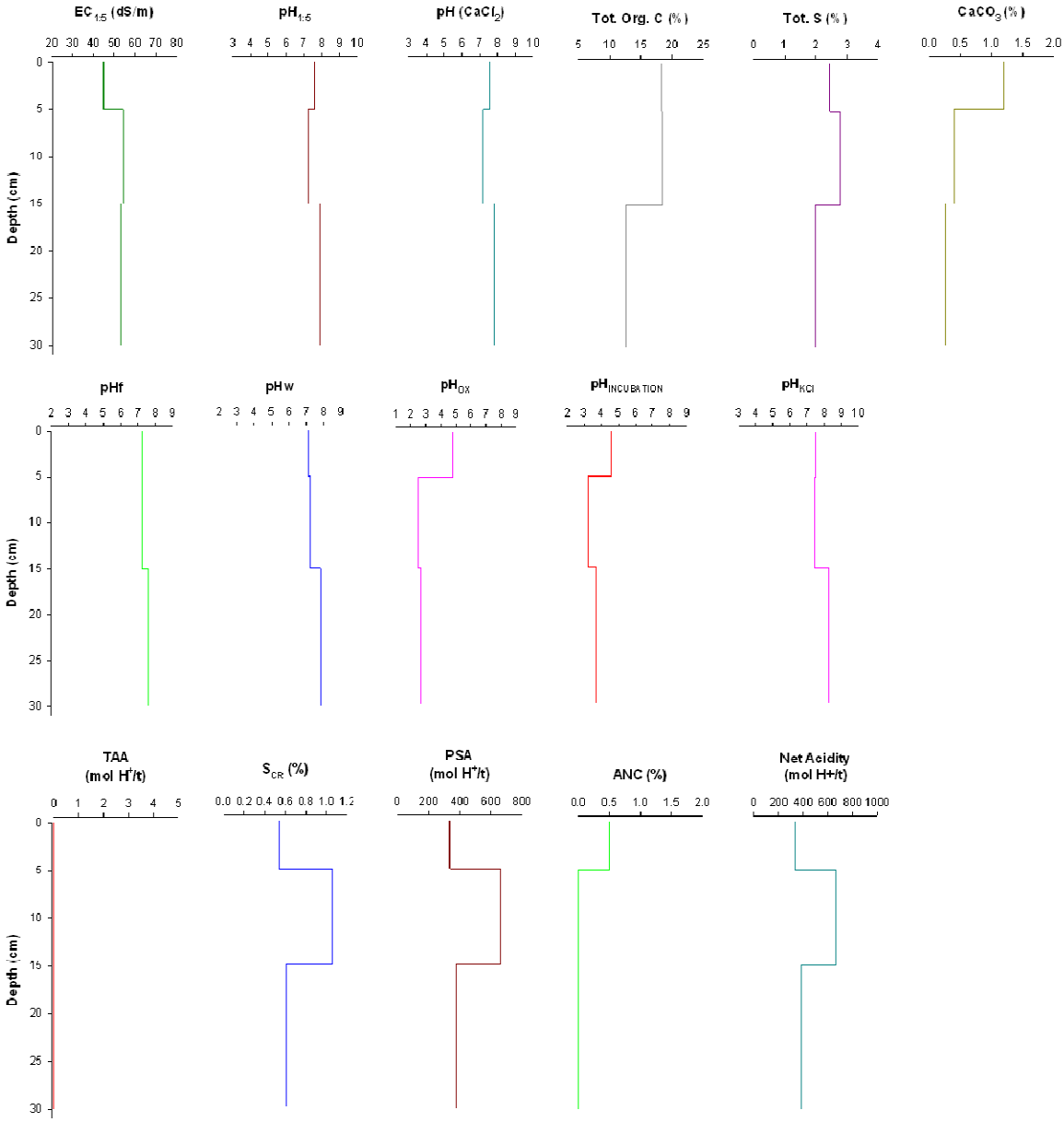


Figure 1-13 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 7

Wet (subaqueous): poorly drained, erosional tidal creek channel, covered by water. Profile BSK 8 – (Table 1-16 and Figure 1-14)

Table 1-16 Summary of soil morphology for profile BSK 8: *Wet: satiated (permanent), very poorly drained, intertidal wetland.* (Soil colour determined moist and consistence dry).

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Oa/W1 (BSK 8-92)	0-5 cm	Black (10YR2/1) organic clay (<5% mineral, >95% sapric and hemic material); no roots; slight H_2S smell.; diffuse boundary	
Oa/W2 (BSK 8-93)	5-15 cm	Dark grey brown (10YR4/2) organic clay (5% mineral, 95% sapric material); no roots; some medium shell fragments; slight H_2S smell; gradual wavy boundary	
Oa/W3 (BSK 8-94)	15-25 cm	Very dark grey brown (10YR2/3) organic clay loam to clay (10% mineral, 90% sapric material); no roots; slight H_2S smell.	

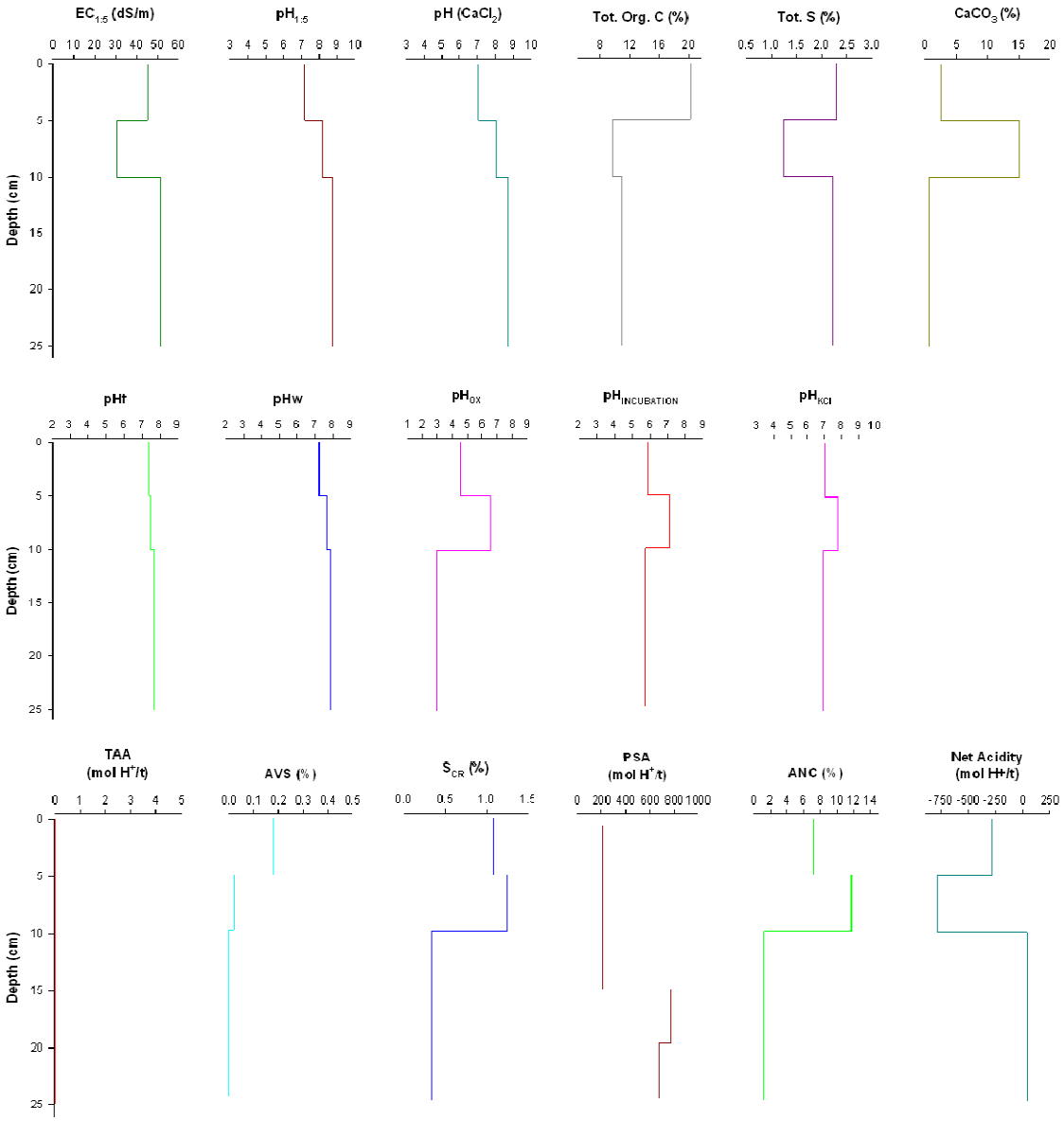


Figure 1-14 Down profile soil chemistry and acid sulfate soil characteristics of profile BSK 8

2. Soil morphology and acid sulfate soil characterisation of the Gillman study site

Gillman is located on the southern side of the Barker inlet, about 10 km south of the St Kilda study site (Figure 2-1). The site was close to 800 ha. Four focus areas were selected to best represent the hydrological and pedological characteristics of the area, and cumulatively covered 11 of the 12 defined map units (Table 2-1).

Focus area A contained map units 1 (Water), 3 (Salt scalded mud flats), 5 (Open low scrub and grasses) and 6 (Open grasslands and shrub). **Focus area B** traversed from an elevated position in the landscape (map unit 6) to the bed of a former tidal creek representation map unit 2 (benthic mat and bare salt scalded mud flat). **Focus area C** traversed across the bund wall at the centre north of the study site (Figure 2-1). On the drained side of the bund wall Focus area C contained map units 1 (Water), 2 (Benthic mat and bare salt scalded mud flat), 3 (Salt scalded mud flats) and 4 (Dense low heath – samphire shrublands). On the tidal (north) side of the bund wall Focus area C contained map units 9 (Water), 10 (Mangrove woodlands) and 11 (Low growing salt marsh plants) (Table 2-1). **Focus area D** was located at the far western portion of the Gillman study site, within the Magazine creek ponding basin (Figure 2-1). Focus area D traversed from the top of a 4.5 m high mound constructed using artificial fill materials (map unit 8) to a low lying area covered by map unit 4 (Dense low heath - samphire shrublands) (Table 2-1). Soil morphology and acid sulfate soil characteristics for 'type' profiles (Table 2-1) are described in the following sections and represent soil types from each of the mapping units.

Landform characteristics for the 'type' profiles described in this Appendix are summarised in Table 2-1. Soil chemical data for these profiles is tabulated in Appendix C.

Table 2-1 Shows soil profiles located within Gillman and that are representative of the map units. Refer to Figure 2-1 for profile locations. Soil profile numbers marked in **red** font are 'type' profiles that were described in detail within Chapter 6 of the thesis and are included here in tables. In addition, soil chemical data for profiles listed in **black** font are given in Appendix C. Profiles numbers listed in **green** font have been described in other soil investigations, such as: (Fitzpatrick 1992; Fitzpatrick *et al.* 1996; Fitzpatrick and Mao 1997; Fitzpatrick *et al.* 2008a; Fitzpatrick *et al.* 2008b; Kinhill Engineering Pty Ltd and McMahon 1996; Merry *et al.* 2003; Thomas and Fitzpatrick 2006a; Thomas 2004; Thomas and Fitzpatrick 2006b; Thomas *et al.* 2004a; Thomas *et al.* 2004b).

Soil profile numbers	Focus area	Map unit no.	Landform	Water State, ponding and drainage
Disturbed former intertidal to supratidal areas				
BG 23, 26, 30, BG P 5	**A, C**	**1.** Water	Erosional channel –stranded tidal creek channel	Wet, poorly drained – permanently inundated >5 cm, (subaqueous soils)
BG 4, 6, 19, 274, 275, 28, 31	**B, C**	**2.** Benthic mat and bare salt scalded mud flats	Erosional channel stranded tidal creek channel	Wet (winter), poorly drained –seasonally inundated > 2 cm
BG 17, 32, BGR 6	**A, C**	**3.** Bare salt scalded mud flats	Open depression - transition from stranded tidal creek to open, flat plain	Wet (winter), poorly drained – rarely inundated
BG 29, GGT 5, 22, RG 1	**C, D**	**4.** Dense low heath - samphire shrublands	Open flat plain – lower former intertidal floodplain	Moist (winter), moderately well drained
BG 1, 15, 16, BGR 7	**A**	**5.** Open low scrub and grasses	Open flat plain – upper former intertidal floodplain	Moist (winter), moderately well drained
BG 3, 5, 7, 8, 9, 10, 11, 12, 14, 18, MFP 1, 2, 8, 9, 21	**A**	**6.** Open grass plain and scrub	Open flat plain – former supratidal zone	Moist (winter), well drained
MFP 14, 19	**na.**	**7.** Bare, scalped, salt scalded sand flats	Open depression – scalped / mined former supratidal zone	Moist (winter), moderately well drained
BG 2, GGT 1, 2, 3, 4	**D**	**8.** Artificially filled areas and embankments	Embankments and raised (filled) former intertidal to supratidal zone	Dry to moist (winter), moderately to poorly drained
Undisturbed intertidal to supratidal areas				
BG 24	**C**	**9.** Water	Erosional channel - tidal creek channel	Wet, poorly drained
BG 21	**C**	**10.** Mangrove woodlands	Open flat –intertidal floodplain	Wet, moderately to poorly drained
BG 20	**C**	**11.** Low growing salt marsh plants	Open flat – intertidal to supratidal zone	Wet, moderately well drained
	na	**12.** Bare chenier ridge – shell grit	Open mound –intertidal to supratidal floodplain	Wet, very well drained

Table 2-2 displays correlations that have been established between landscape features and soil characteristics. In Chapter 7 these associates were used to produce soil maps covering the full extent of the Gillman and St Kilda study sites. Map units are also linked to acid sulfate soil hazards.

Table 2-2 Map units located within Gillman Focus areas A, B, C and D combined with soil profiles classified according to Soil Taxonomy (Soil Survey Staff 2010), the Australian Soil Classification (Isbell 2002) and using acid sulfate soil terminology (Sullivan *et al.* 2010).

Map unit no. (unit colour)	Soil profile no.	Australian Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid Sulfate Soil materials
Disturbed former intertidal to supratidal areas (Gillman study site)				
1. Water	**BG 30 BG P 5**	Sodosolic Salic Hydrosol Sodosolic Salic Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic
2. Benthic mat, bare salt scald, mud flats	**BG 4, 28, 31**	Sulfuric, Hypersalic Hydrosol Epicalcareous, Hypersalic Hydrosol Haplic, Hypersalic Hydrosol	Salidic Sulfaquepts Typic Halaquepts Aeric Halaquepts	Hypersulfidic, hyposulfidic, monosulfidic
3. Bare salt scalded mud flats	**BG 17, 32**	Sulfuric, Salic Hydrosol Haplic, Hypersalic Hydrosol	Salidic Sulfaquepts Aeric Halaquepts	Sulfuric, hypersulfidic, hyposulfidic, monosulfidic
4. Dense low heath -samphire shrublands	**BG 22, GGT 5**	Haplic, Hypersalic Hydrosol Sulfuric, Salic Hydrosol	Aeric Halaquepts Typic Sulfaquepts	Sulfuric, hyposulfidic
5. Open low scrub - grasses	**BG 15**	Sulfuric, Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hypersulfidic
6. Open grass plain and scrub	**BG 11, 5**	Sulfuric, Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hypersulfidic, hyposulfidic
7. Bare, scalped, salt scalds, sand flat	**MFP 14**	Sulfuric, Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hypersulfidic, hyposulfidic
8. Artificially filled areas and embankments	**GGT 2**	Sulfidic, Dredgic Anthroposol	Haplic Xerarents	Hypersulfidic, hyposulfidic, monosulfidic
Undisturbed intertidal to supratidal areas (Gillman study site)				
9. Water	**BG 24**	Hemic, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic
10. Mangrove woodlands	**BG 21**	Hemic, Sulfidic, Intertidal Hydrosol	Sulfic Hydrowassents	Hypersulfidic, hyposulfidic, monosulfidic
11. Low growing salt marsh plants	**BG 20**	Hemic, Sulfidic, Intertidal Hydrosol	Sulfic Hydrowassents	Hypersulfidic, hyposulfidic, monosulfidic

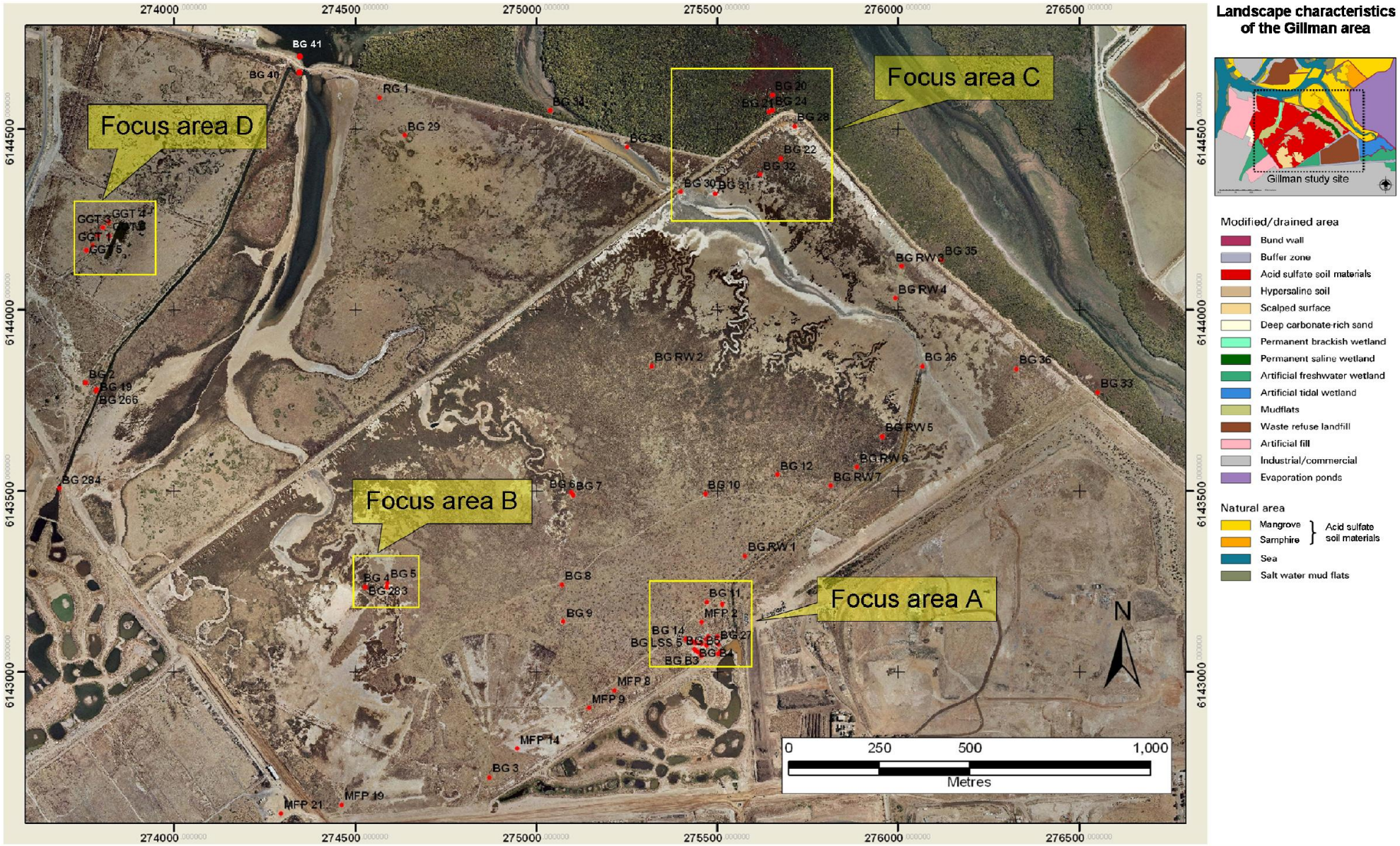


Figure 2-1 Gillman study site indicating localities of four focus study areas. Focus area – A is located in the former supratidal zone and transects from a topographical high (surficial geomorphology is sandy shoreface facies), to topographically low surficial geomorphology includes supratidal marsh and back barrier sands). Focus area – B transects across a well defined stranded tidal creek that is seasonally inundated. Focus area – C transects the bund wall, from former (drained) intertidal zone to the undisturbed intertidal zone. Focus area – D transects from exposed former intertidal zone (dominated by mangrove peats) to intertidal soils which have been buried (re-claimed) using imported fill material. Main landscape features are summarised on the inset map.

1.4. Descriptive soil toposequence process models for a drained supratidal landscape

1.4.1. Gillman Focus area A

Focus area A is situated on the leeward (eastern) side of a geomorphically controlled relic sandy shore face, which forms a slight north-east projecting ridgeline covered dominantly by salt tolerant grasses. Prior to the construction of bund walls which drained this area in 1935 the sandy ridgeline was likely supratidal and covered by thick samphire marsh vegetation (Belperio and Rice 1989; Burton 1982). This rectangular bunded area was used as the 'over-shoot' area for the Dean rifle range until 2003. Focus area A encompasses a toposequence that transects from the relatively high sand ridge, across lower lying back barrier sands and clays to a permanently inundated 'constructed' saline wetland pond (the outfall pond of the Range Wetlands). Four map units occur within focus area A. The soil types that underlay these map units are represented by four soil profiles that form a north-south toposequence that transects from the topographically elevated "open grass plain and scrub" to low-lying permanent "water" (Figure 2-2 and Figure 2-3). The four soil profiles are; BG 11, BG 15, BG 17 and BG P 5 (Table 2-3). Table 2-4 provides a summary of soil taxonomy for 'type' soil profiles in Gillman focus area A.

Table 2-3 Soil profiles selected to be representative of map units occurring within focus area A, and along toposequence transect A-A' in Figure 2-2 and Figure 2-3.

Soil profile numbers	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Disturbed intertidal to supratidal areas (Gillman study site)				
BG 11	2.5 m AHD	**6.** Open grass plain and scrub	Open flat plain – former supratidal zone	Moist (winter), well drained
BG 15	2.0 m AHD	**5.** Open low scrub and grasses	Open flat plain – upper former intertidal floodplain	Moist (winter), moderately well drained
BG 17	1.5 m AHD	**3.** Bare salt scalded mud flats	Open depression - transition from stranded tidal creek to open, flat plain	Wet (winter), poorly drained – rarely inundated
BG P 5	0.3 m AHD	**1.** Water	Erosional channel – stranded tidal creek channel	Wet, poorly drained – permanently inundated >5 cm, (subaqueous soils)

Table 2-4 Gillman focus area A soil profiles are classified according to Australian Soil Classification (Isbell 2002), Soil Taxonomy (Soil Survey Staff 2010) and using acid sulfate soil terminology.

Soil profile number	Map unit	Aust. Soil Classification (Isbell 2002)	Soil Taxonomy (Soil Survey Staff 2010)	Acid Sulfate Soil materials present	Significant net acidity occurrence
BG 11	**6.** Open grass plain and scrub	Sulfuric Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hypersulfidic hyposulfidic	190 cm @ 203 mole H^+/t from 50 cm depth
BG 15	**5.** Open low scrub and grasses	Sulfuric Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hypersulfidic	105 cm @ 1903 mole H^+/t from 65 cm depth
BG 17	**3.** Bare salt scalded mud flats	Sulfuric Salic Hydrosol	Salidic Sulfaquepts	Sulfuric, hypersulfidic	95 cm @ 1491 mole H^+/t from 25 cm dept including AVS content of h
BG P 5	**1.** Water	Sodosolic Salic Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic	5 cm @ 456 mole H^+/t from 0 cm depth, including an AVS content of 1.1%

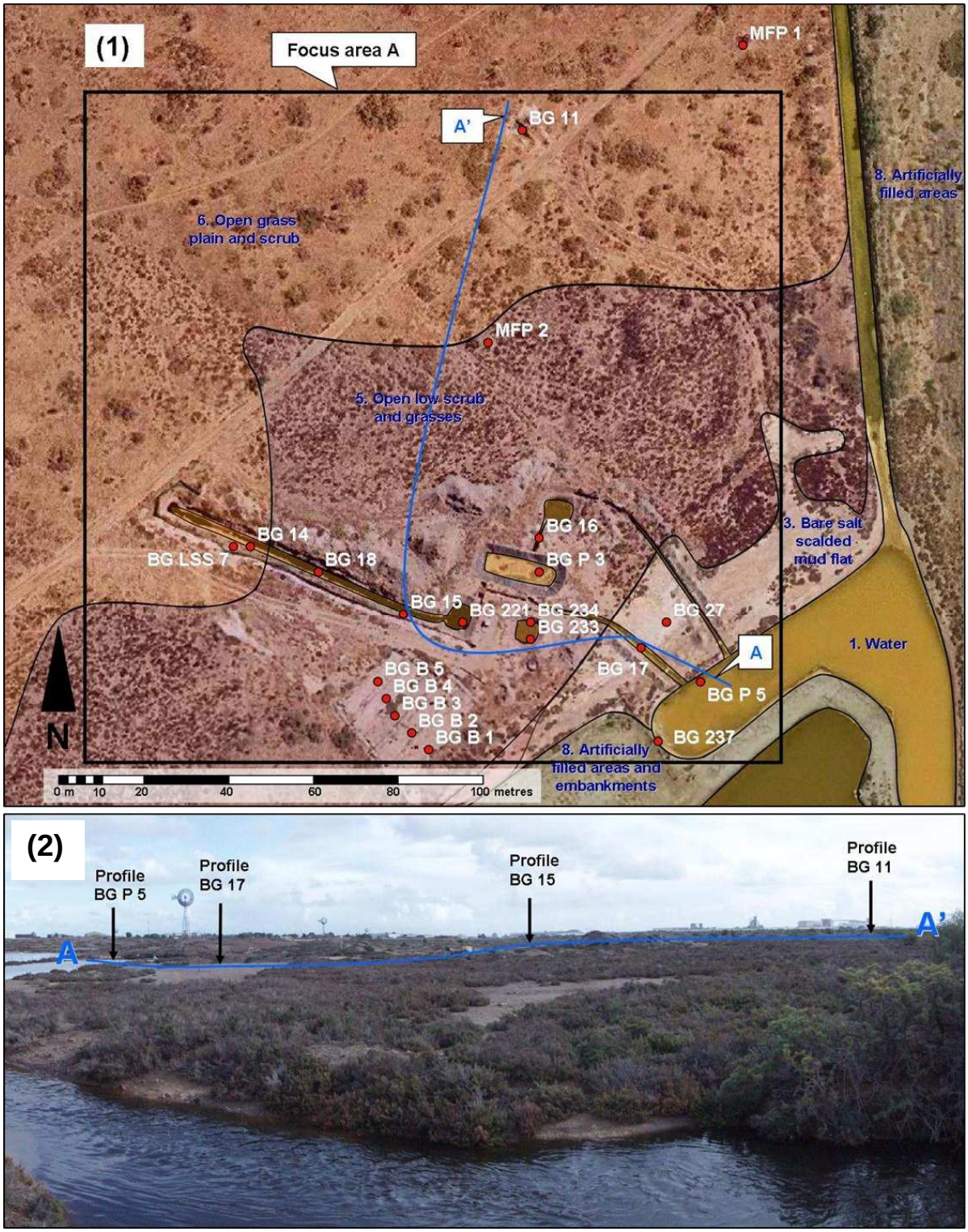


Figure 2-2 (1) Detailed aerial photograph of focus area A showing the location of soil profiles and map units; (2) oblique photograph showing general landscape characteristics of focus area A.

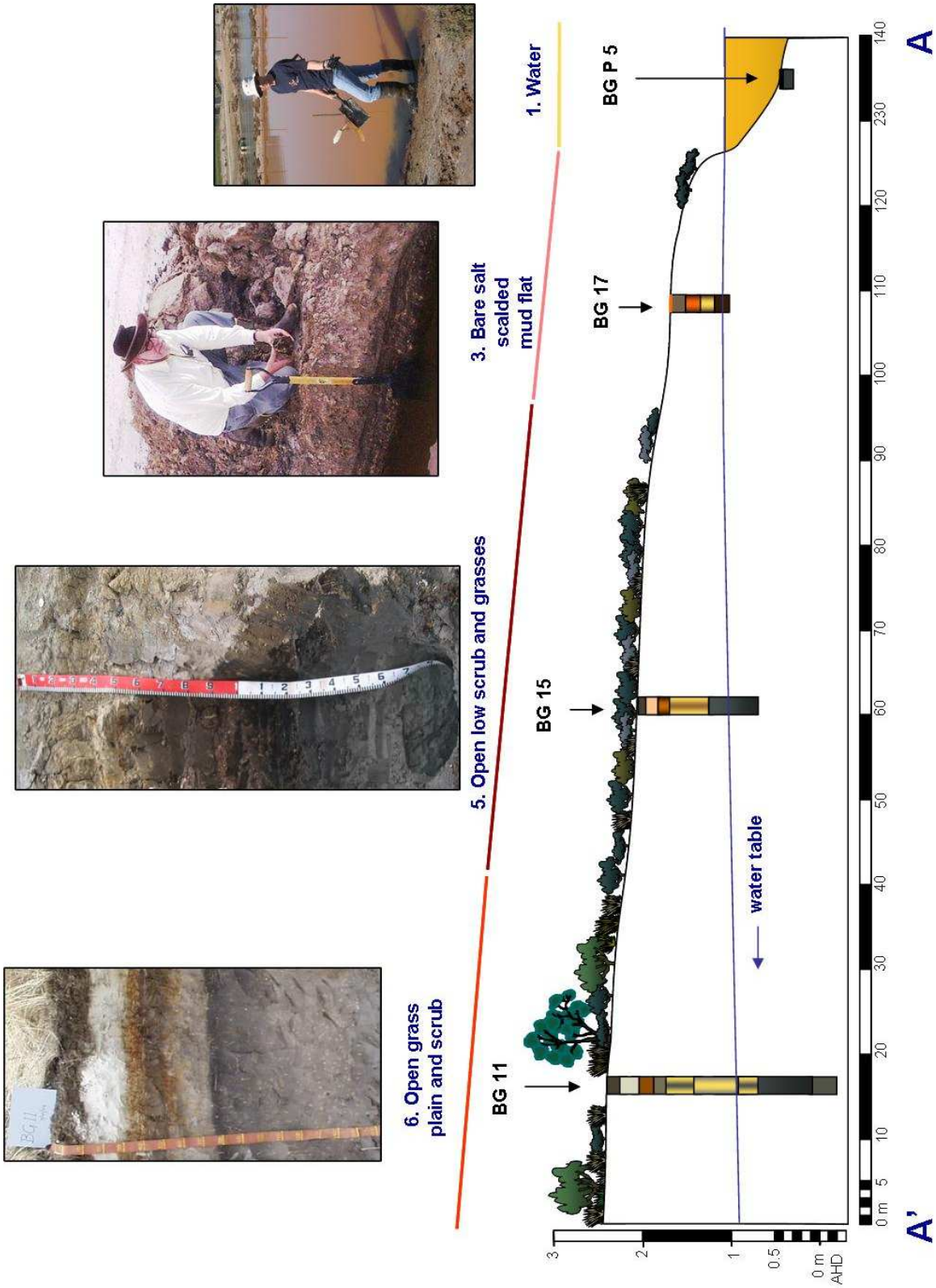


Figure 2-3 Descriptive soil-regolith toposequence model (cross section A-A' shown in Figure 6-2) indicating map units, position of representative soil profiles with colour photographs and average water table depth and groundwater flow direction.

Map unit 6 - ***Moist (winter): well drained, open grass plain and scrub – former supratidal zone. Profile BG 11*** (Table 2-3 and Figure 2-4)

Table 2-5 Summary of soil morphology for profile BG 11: *Dry to moist, well drained, open flat plain – former supratidal zone.* Soil colour was determined on moist samples and consistence on dry samples. Photos are of dried bulk samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (frame size: 5 x 2.5 cm)
Oe (BG 11-204)	0-10	Very dark greyish brown (10YR3/2) silt loam without mottles; moderate coarse subangular blocky structure; weak consistency without coarse fragments; abundant fine roots; gradual and smooth boundary	
A (BG 11-205)	10-12	Dark greyish brown (10YR4/2) silt loam with common fine, faint, dark yellowish brown (10YR4/4) mottles inside the peds; strong fine subangular blocky structure; medium consistency without coarse fragments; common fine roots; sharp and wavy boundary	
2E1 (BG 11-206)	12-30	Light grey (10YR7/2) sand without mottles; single grain structure; very weak consistency without coarse fragments; non calcareous; very few roots; gradual and irregular boundary	
2Ey2 (BG 11-207)	30-40	Light grey (10YR7/2) loamy sand with prominent, strong brown (7.5YR5/6) mottles along root channels (50% volume); single grain structure; weak consistency; without coarse fragments; non calcareous; very few roots. Discontinuous lenses of shells, 5 cm thick, above the lower boundary, weathered, oxidized; abrupt and smooth boundary	
3Bty1 (BG 11-209)	40-49	Dark grey (10YR4/1) medium clay with pale yellow (2.5Y7/4) mottles (30% volume) of jarosite around root channels; and some prominent, 2 mm thick, brown (7.5YR5/4) mottles of Fe-ox coating or infilling root channels; weak, medium subangular blocky structure; non calcareous; very few living roots, common dead roots; abrupt and smooth boundary	
4Bjy1 (BG 11-210)	49-58	Very dark greyish brown (10YR3/2) clayey sand with pale brown (10YR6/3) prominent mottles (30% volume) of jarosite around root channels, up to 5 mm thick, and some distinct dark brown (7.5YR4/4) mottles of Fe-ox coating root channels; weak, subangular blocky structure; non calcareous; very few living roots, common dead roots; gradual and smooth boundary	
4Bj2 (BG 11-211)	58-78	Dark grey (10YR4/1) medium sand with prominent light yellowish brown (2.5Y6/4) mottles (10% volume) of jarosite around root channels, up to 5 mm thick, and some distinct dark brown (7.5YR4/4) mottles of Fe-ox around root channels; weak, subangular blocky structure; non calcareous; no roots; clear and smooth boundary	
4Bjg3 (BG 11-214)	78-100	Very dark grey (10YR3/1) medium sand with prominent light yellowish brown (2.5Y6/4) mottles (5%:volume) of jarosite around root channels, up to 5 mm thick with a sandy texture; weak single grain structure; non calcareous; no roots; gradual and smooth boundary	
4Bg4 (BG 11-215)	100-160	Light brownish grey (10YR6/2) medium sand with prominent, light brownish grey (2.5Y6/2) mottles (5% volume) of jarosite around root channels, up to 5 mm thick with a sandy texture; weak single grain structure; non calcareous; no roots; diffuse and irregular boundary	

4Bg5 (BG 11-216)	160-195	Dark greyish brown (10YR4/2) medium sand with prominent olive yellow (2.5Y6/6) mottles (5% volume) of jarosite around root channels, up to 5 mm thick with a sandy texture, and some very dark grey (2.5Y3/0) mottles (1% volume) of sulfidic material, as an outer rim of the jarosite mottles; weak single grain structure; non calcareous; no roots and diffuse boundary	
4Bg6 (BG 11-217)	195-205	Dark greyish brown (10YR4/2) medium sand with some diffuse olive yellow (2.5Y6/6) mottles (2% volume) of jarosite in matrix and some very dark grey (2.5Y3/0) mottles (5% volume) of sulfidic material in matrix; weak single grain structure; non calcareous; no roots and diffuse boundary	
4Bg/W7 (BG 11-218)	205-240	Dark greyish brown (10YR4/2) (sulfidic) medium sand with abundant black (10YR2.5/1) mottles (10% volume) due to charcoal residues and charcoal fragments; single grain structure; non calcareous; no roots and diffuse boundary	
5Bg/W1 (BG 11-219)	240-300	Brown (10YR5/3) clay sand with clay content increasing with depth; no mottles; non calcareous; no roots	
5Bg/W2 (BG 11-220)	300-350	Brown (10YR5/3) sandy clay with clay content increasing with depth and colour darkening (10YR4/3) with depth; no mottles; non calcareous; no roots	

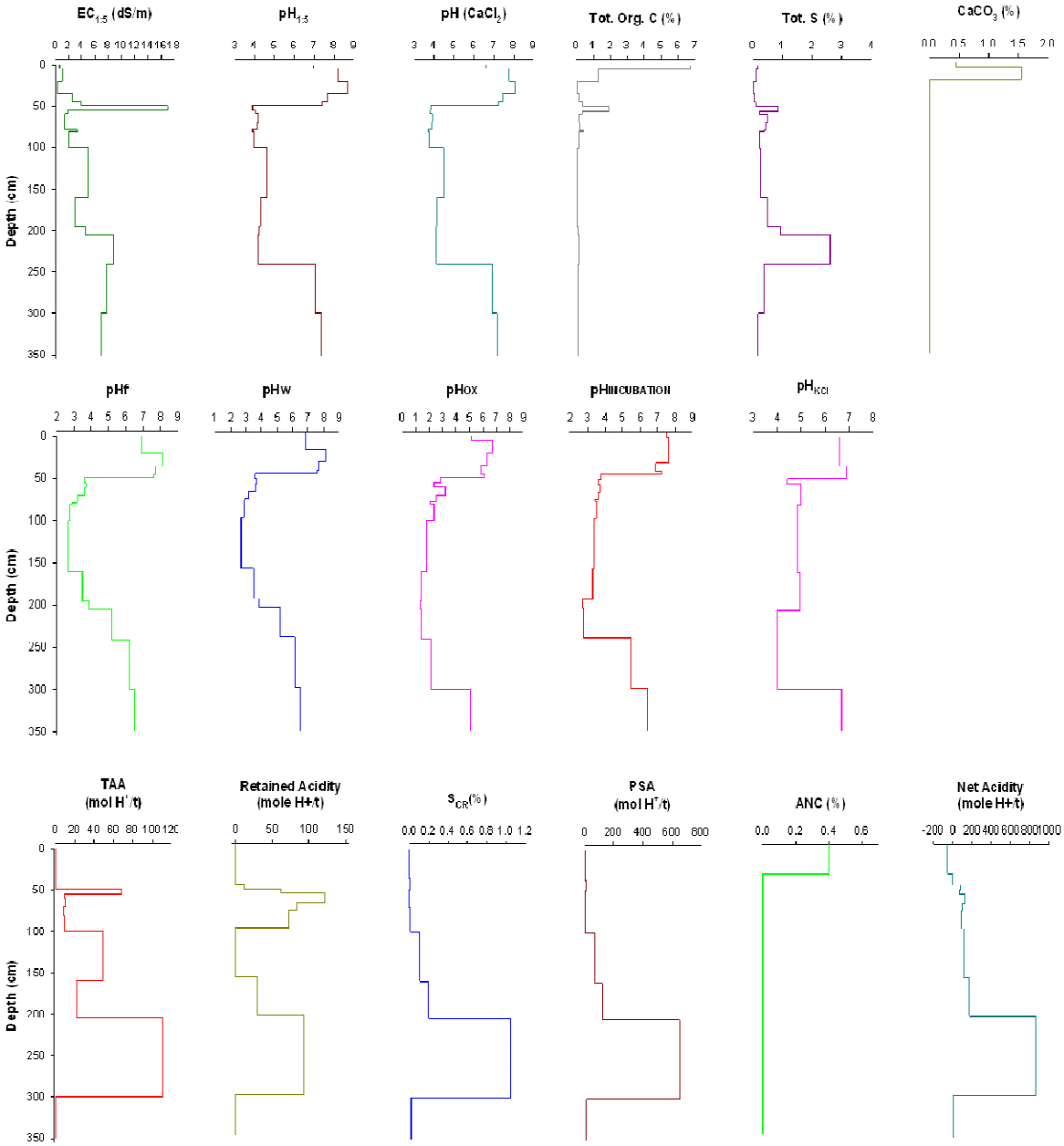


Figure 2-4 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 11.