Coastal acid sulfate soil processes in Barker Inlet, South Australia

Doctor of Philosophy

The University of Adelaide

School of Earth and Environmental Sciences

Brett P. Thomas

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Chapter Six

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

The prime objective of this chapter is to identify and characterise representative descriptive toposequence processes models for the non-tidal and intertidal areas of the Gillman study site by summarising key soil morphological and classification information across each toposequence.

Gillman is located on the southern side of the Barker inlet, about 10 km south of the St Kilda study site (Figure 3-1). Due to the large size (close to 800 ha) and environmental heterogeneity of the Gillman study site, **four focus areas** were selected for detailed study. The focus areas were selected to best represent the hydrological and pedological characteristics of the site, and cumulatively covered 11 of the 12 mapping units defined in Table 6-1. **Focus area A** was located about 1 km south of the bund wall and traversed from a prominent position in the landscape to a low lying position at the outlet pond of the 'Range wetlands' (Figure 6-1). Focus area A contained map units 1 (Water), 3 (Salt scalded mud flats), 5 (Open low scrub and grasses) and 6 (Open grass plain and shrub). **Focus area B** was located about 1 km to the west of Focus area A and traversed from an elevated position in the landscape (map unit 6) to the bed of a former tidal creek representing 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 6-1). 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 6-1). **Focus area D** was located at the far western portion of the Gillman study site, within the Magazine creek ponding basin (Figure 6-1). 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 6-1). Soil morphology and acid sulfate soil characteristics for 'type' profiles (Table 6-1) are described in the following sections and represent soil types from each of the map units.

To make the chapter length manageable, only one soil profile from each of the map units is described in detail in the text. The other 'type' profiles are summarised here, and full descriptions are provided in Appendix B.

Table 6-1 Soil profiles located within focus areas that are representative of the map units. Refer to Figure 6-1 for profile locations. Soil profile numbers marked in **red** font are 'type' profiles that are described in detail within this chapter and Appendix B. In addition, soil chemical data for all other profiles (i.e. in black font) are given in Appendix C. Other profiles (black text) were used for refining map unit boundaries and are described in unpublished reports.

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, 34, 41	**C**	**9.** Water	Erosional channel - tidal creek channel	Wet, poorly drained
BG 21, 35	**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

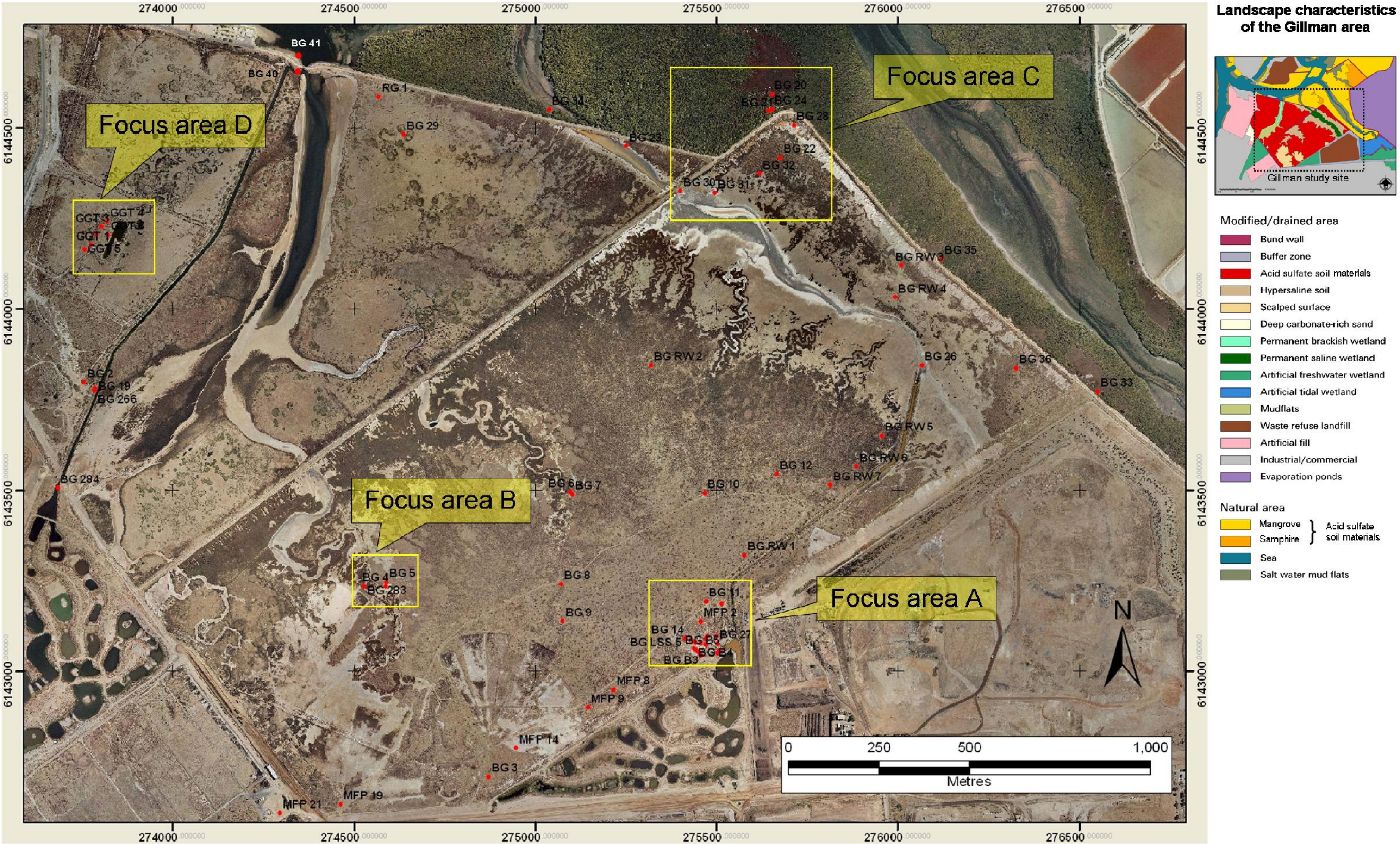


Figure 6-1 Gillman study site indicating localities of four focus study areas. Focus area – A is located in the former supratidal zone and transects from a topographical high (surficial geomorphology is sandy shoreface facies), to topographically low surficial geomorphology includes supratidal marsh and back barrier sands). Focus area – B transects across a well defined stranded tidal creek that is seasonally inundated. Focus area – C transects the 3.5 m high 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. The small map and legend on the side bar indicate general landscape characteristics for the Gillman area.

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

6.1.1. 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 predominantly covered by salt tolerant grasses. The ridgeline is evident from aerial photography and on the digital elevation map (Figure 3-6), with an elevation ranging from 1.8 to 2.8 m AHD. 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 1982b). 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 6-2 and Figure 6-3). The four soil profiles are; BG 11, BG 15, BG 17 and BG P 5 (Table 6-2).

Table 6-2 Soil profiles selected to be representative of map units occurring within focus area A, and along toposequence transect A-A’ in Figure 6-2 and Figure 6-3.

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)

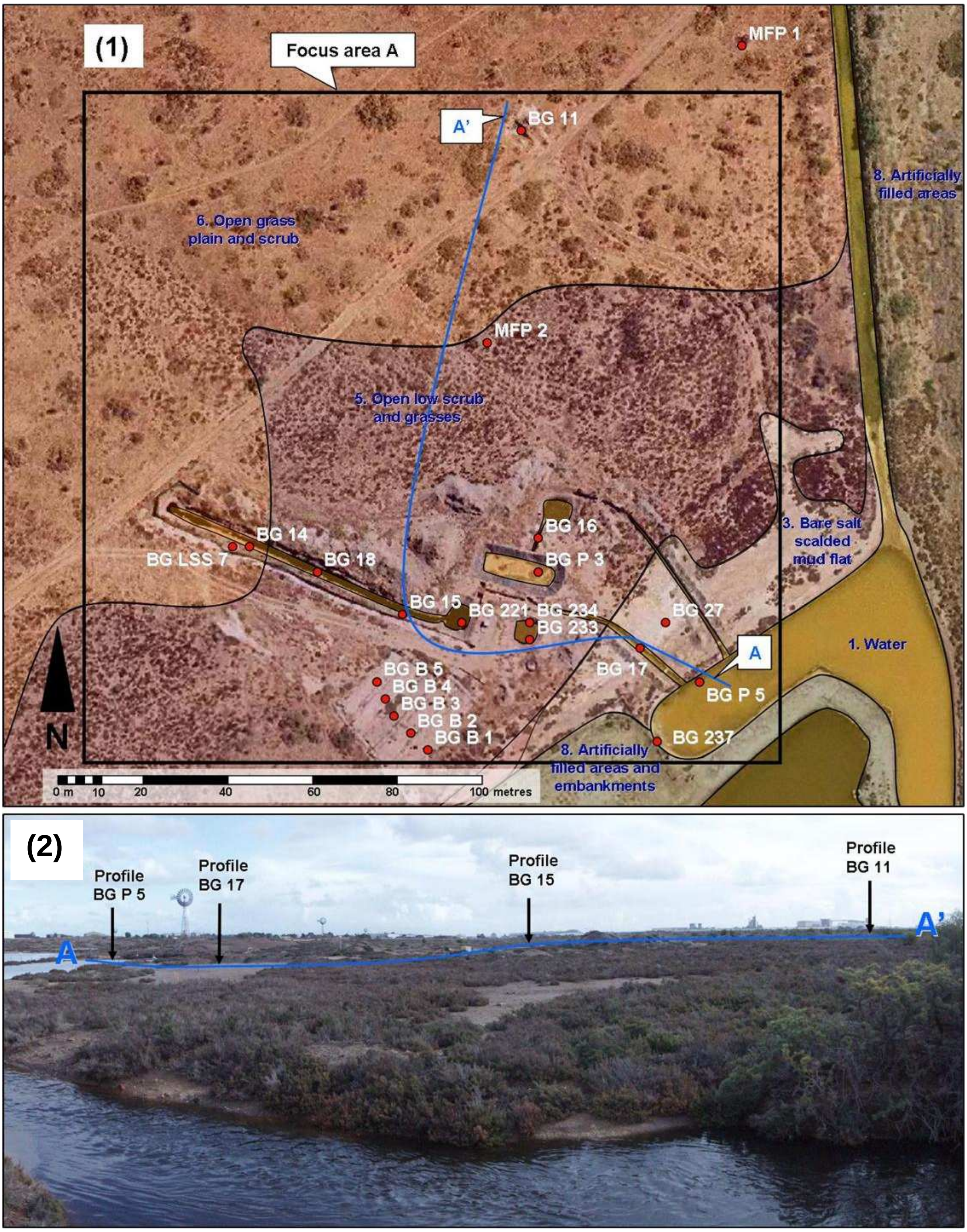


Figure 6-2 (1) Detailed aerial photograph of focus area A showing the location of soil profiles and map units; (2) oblique photograph showing general landscape characteristics of focus area A.

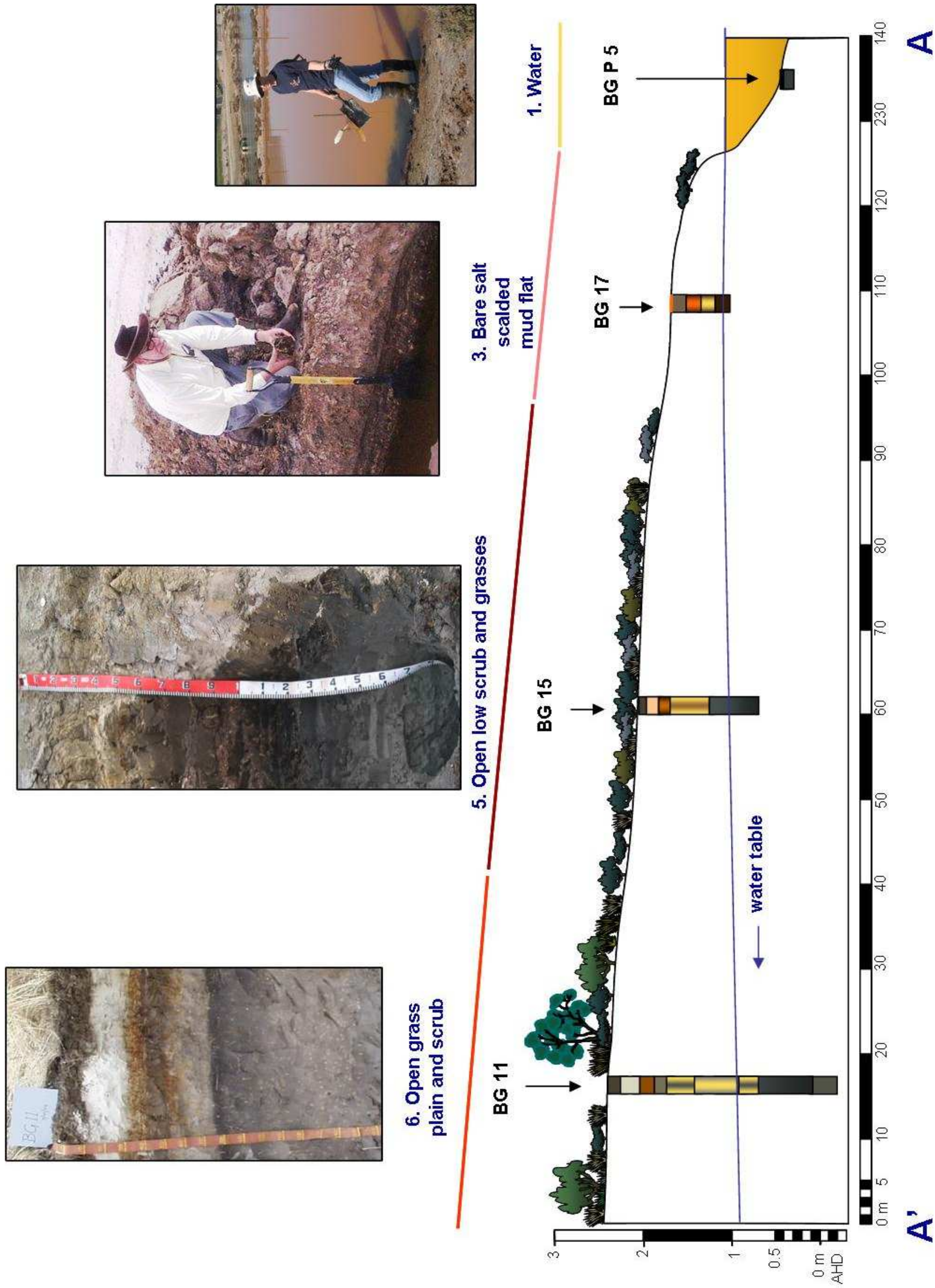


Figure 6-3 Descriptive soil-regolith toposequence model (cross section A-A' shown in Figure 6-2) indicating map units, position of representative soil profiles with colour photographs and average water table depth and groundwater flow direction. Detailed descriptions for the four profiles are given in Table 6-3 (BG 11), Table 6-4 (BG 15), Table 6-5 (BG 17) and Table 6-6 (BG P 5).

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

Soil profile BG 11 occurs within map unit 6 (Open grass plain and scrub). A detailed summary of the soil morphological features together with a corresponding close-up photograph of soil fragments are given in Table 6-2. Profile BG 11 was originally developed in a supratidal regime but tidal inundation was totally excluded in 1935 when a bund wall was constructed causing oxidation of sulfidic material. The parent material consists of several layers of lacustrine and tidal sediments deposited under mangrove and supratidal samphire vegetation.

The near surface horizons (Oe and A) were dry to slightly moist (due to recent rainfall events when sampled), well drained, firm and have a well developed (strong) subangular blocky structure. Root mass of salt tolerant grasses and breakdown of organic matter formed an organic horizon (Oe) at the top of the profile (0-10 cm). The organic matter content of the Oe horizon was approximately 6.8 % and was predominantly uniform dark reddish-brown with no evident redoximorphic features. The underlying A horizon (10-12 cm) had minor Fe-oxide mottles along ped surfaces and 1.5% $CaCO_3$. Organic matter decreased with depth in the A horizon, E and B horizons to generally < 1%. The E horizons (2E1 and 2Ey2) had a weak consistency and a very sharp upper boundary (at 12 cm). These horizons consist of light grey, well sorted medium sands with low amounts of organic matter and few redoximorphic features except near the lower boundary of the 2Ey2 horizon (from 30-40 cm) where frequent iron mottles were associated with remnant root channels and coarse shell fragments. Between the O and B horizons discontinuous lenses of decalcifying, coarse shell fragments occurred. Below 40 cm, in the B horizons, the soil profile remained moist due to wicking of acidic, saline groundwater. Below 160 cm all soil horizons remained permanently saturated. The 3Bty1 horizon occurs directly below the 2Ey2 horizon and consists of a dark greyish brown layered clay with distinct reddish-brown iron oxide mottles along remnant root channels, and has a weak consistency. Gypsum crystals are clearly visible using a hand lens. Above the permanent groundwater table (at 160 cm) the B horizon consists of five definable horizons, with three more B horizons occurring below the water table. Horizon 4Bjy1 (49-58 cm) contains some dark greyish brown clay but in a much sandier matrix than 3Bty1 (40-49 cm). Jarosite mottles have formed around elongate, vertically-oriented macropores (remnant from mangrove pneumatophores) and have a thin layer of reddish-brown iron oxide coatings surrounding them. The underlying 4Bj2, 4Bjg3 and 4Bjg4 horizons (occurring from 58 cm to 160 cm) have similar redoximorphic features to 4Bjy1 (49-58 cm), but in a sandier, dark grey to light brownish grey matrix. Jarosite mottles become more prominent and abundant with depth until the winter water table is reached at about 100 cm. Horizon 4Bjg5 occurs below 160 cm and consists of weak sand with a dark grey matrix and some slightly darker grey (sulfidic) mottles (Table 6-3). The matrix and mottles in this horizon have a chroma of 2 or less and are therefore considered to be reduced due to the presence of Fe^{2+} (Schoeneberger *et al.* 2002).

Table 6-3 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, oxidised; 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	
4Bjg4 (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	
4Bjg5 (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	

Although soil colour is a good indicator of redoximorphic conditions in a soil profile, it should not be used in isolation from physical indicators such as Eh (redox potential) and mineralogy (refer to Chapters 8 and 10). The occurrence of yellow jarosite mottles in the sandy matrix is rare and only occurs along larger remnant pores (mangrove pneumatophores). Horizons 4Bg6 and 4Bg/W7 occur from 195 cm to 240 cm and consists of a dark greyish brown, sandy matrix with abundant black mottled sand. Horizon 5Bg/W2 occurs from 240-350 cm and consists of a brown sandy loam with no mottles. Clay content increased with depth below the 5Bg/W1 horizon.

Soil EC generally increased with depth and ranged from 0.6 in the surface layer to 6.9 dS/m at the base of the profile. Clay rich layer 4Bjy1 had an EC of 17.0 dS/m. Soil pH (1:5) was near neutral for the upper 49 cm of the profile and was acidic between 49 and 240 cm depth. Soil pH (1:5) of the acidic part of the profile ranged between 3.9 and 4.6 (Figure 6-4). Soil pH_{CaCl_2} results were very similar to pH (1:5) values, but were about 0.2 to 0.3 of a pH unit lower. Total organic carbon contents were highest (6.8%) at the surface and decreased with depth to 0.1% at the base of the profile. Total sulfur measurements increased with depth and ranged from 0.1% at the surface layer to a maximum of 1.3% at 205 cm depth (Figure 6-4). Carbonate content was highest in the near surface A horizon, measuring 1.6% $CaCO_3$, and was not detected in the underlying layers.

Soil profile BG 11 classifies as: Typic Sulfaquepts (Soil Survey Staff 2010); Sulfuric Salic Hydrosol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil-water pH (pHw) data (Figure 6-4) show that soil layers above 49 cm (Oe, A, 2E1, 2Ey2 and 3Bty1) are circum-neutral. Soil layers between 49 and 195 cm depth (4Bjy1, 4Bj2, 4Bjg3, 4Bjg4, 4Bjg5,) were strongly acidic, with a mean pH_W of 3.3 for the depth interval. Below 205 cm depth (horizons 4Bg6, 4Bg/W7, 5Bg/W1, 5Bg/W2) were slightly acidic, with pH_W ranging from 5.2 to 6.5 (Figure 6-4). Peroxide oxidation tests (pH_{OX}) were performed on all samples to gauge the likely presence of sulfidic materials (See Chapter 4). The pH_{OX} dropped by > 1 pH unit to less than 2.5 in 8 soil samples, however only one of these soil samples had a starting pH above 4 (Figure 6-4). The pH_{OX} results suggest that much of the sulfuric material in this profile is likely to still contain pyrite. After incubating soil samples for 19 weeks, only one sample (from layer 4Bg/W7) showed a drop in pH of at least 0.5 pH unit to less than pH 4, which is likely due to sulfide oxidation, according to S_{CR} analysis data. Some incubated samples containing sulfuric material showed a rise in of between 0.5 and 1.0 pH unit.

Existing Acidity (Titratable actual acidity (TAA) and Retained acidity)

Eight of the 9 samples analysed had a pH_{KCl} of < 6.5, indicating they contain Existing Acidity as TAA, and had no acid effective neutralising capacity. TAA ranged between zero, at the top and bottom of the soil profile, and 49 mole H^+/tonne of soil (in layer 4Bjg4) and a mean of TAA of 10.3 mole H^+/tonne for the profile. Retained acidity was measured in 7 samples, only 2 of which had a pH_{KCl} of < 4.5. Retained acidity ranged from zero at the top and base of the soil profile to 122 mole H^+/tonne of soil (in layer 4Bj2) and a mean value of 40 mole H^+/tonne for the profile (Figure 6-4).

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was determined for 9 layer samples within soil profile BG 11 (Figure 6-4). S_{CR} values ranged form 0% and 1.05%, with 6 soil layers containing detectable S_{CR} (of 0.01% or above), indicating that they contain Potential Sulfidic Acidity. The highest S_{CR} values occurred low down in the soil profile, within gleyed, sandy soil layers below 160 cm. No samples were analysed for AVS due to there being only a minor occurrence of dark grey to black mottles. AVS were therefore considered not to be significant in any of the soil layers in profile BG 11.

Acid Neutralising Capacity (ANC)

Near surface soil samples (between 0 and 49 cm) contained minor ANC with up to 0.4% $CaCO_3$. Between 49 cm and 300 cm depth, soil samples measured a pH_{KCl} below 6.5 (Figure 6-4), and by definition they contain zero ANC (refer to Ahern *et al.* 2004).

Net Acidity

The topsoil layer of profile BG 11 had a Net Acidity value of -53 mole H^+/tonne (Figure 6-4), and is therefore net alkaline. All other soil layers had positive Net Acidity values, which ranged between 7 and 764 mole H^+/tonne (occurring at 205 cm depth) (Figure 6-4). The mean Net Acidity value for profile BG 11 was 120 mole H^+/tonne.

Acid sulfate soil materials: In accordance with the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG 11 classifies as an acid sulfate soil, containing: sulfuric material with both hypersulfidic and hyposulfidic materials.

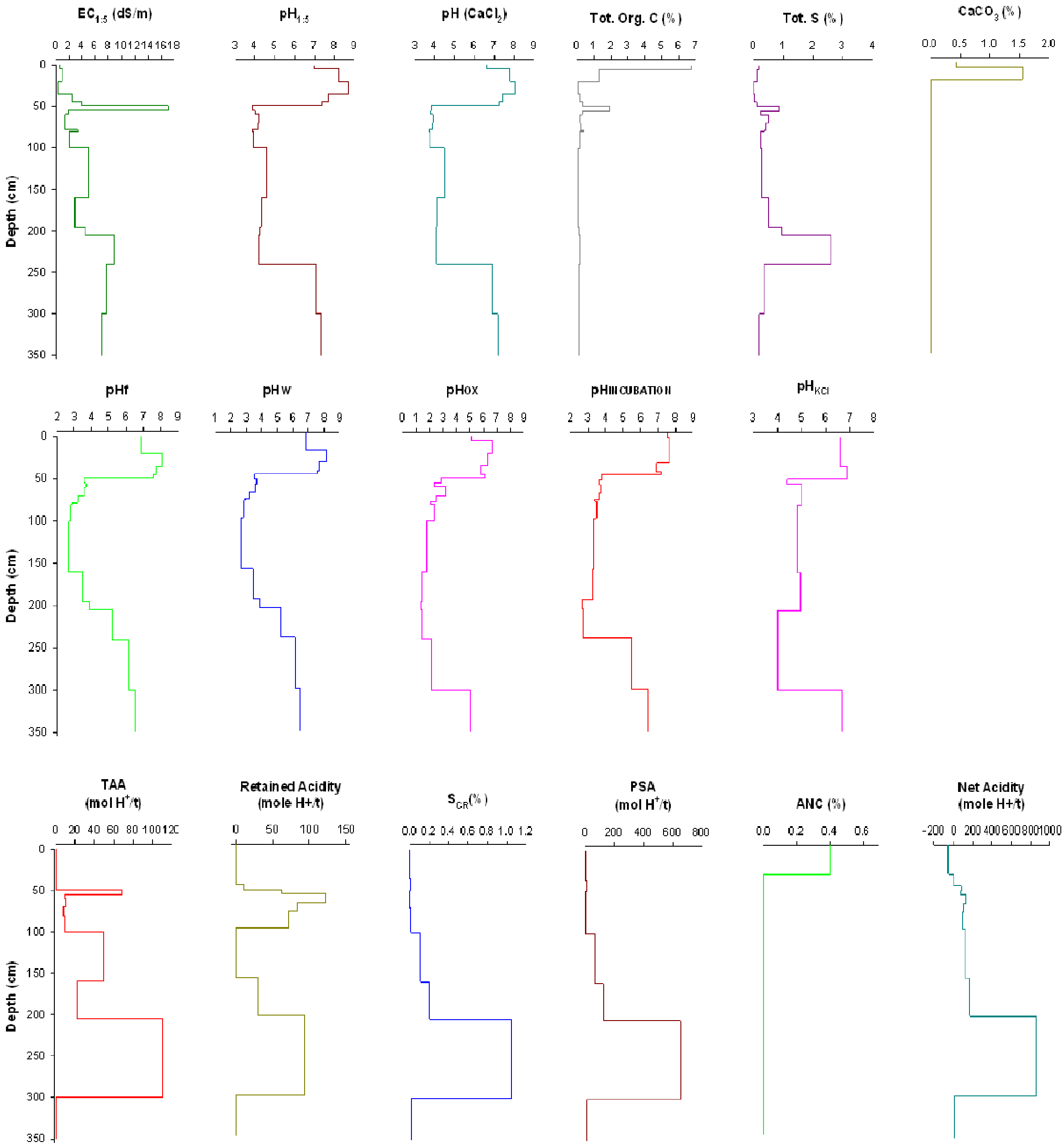


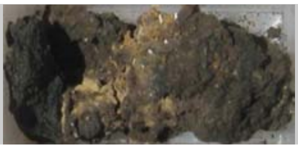
Figure 6-4 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 11.

Map unit 5 - ***Moist (winter): moderately well drained, open low scrub and grasses – lower former intertidal floodplain. Profile BG 15***

Soil profile BG 15 occurs within map unit 5 (Open low scrub and grasses). Soil morphology for profile BG 15 is provided in Table 6-4, together with a corresponding close-up photograph of soil fragments. Profile BG 15 originally developed in an upper intertidal regime but tidal inundation was totally excluded in 1935 when a bund wall was constructed causing oxidation of sulfidic materials. The parent material consists of several layers of lacustrine and tidal sediments deposited under mangrove and supratidal samphire vegetation. The surface horizons (Oe and A) were dry to slightly moist, moderately well drained brown to greyish brown, firm cracked clay. Strong brown mottles are evident in the pale yellow (slightly bleached) silty clay E horizons, along with a few white specks of gypsum. The underlying B horizons (40 to 95 cm) and 5Oijg horizon are greyish brown sandy clays and sandy peats with clear, pale brown to pale yellow jarosite mottles (up to 25% volume) that occur along larger pores (mangrove pneumatophores) and within the soil matrix. Jarosite mottles are less common below 110 cm, in wet, gleyed, greyish brown, sandy horizons. Horizon 7Bg/W1 was the deepest layer recorded and occured between 150 and 170 cm depth, and consisted of brown sandy clay with no mottles.

Soil EC measured 0.8 dS/m at the surface and increased with depth to a maximum of 45.2 dS/m at 110 cm. This hypersaline soil layer occurred approximately at the summer groundwater table. Soil pH (1:5) was near neutral for the upper 25 cm of the profile and then was acidic to 170 cm depth. The soil pH (1:5) of the acidic portion of the profile ranged between 2.3 and 4.4 (Figure 6-5) Soil pH_{CaCl_2} results were very similar to pH (1:5) values, but were about 0.1 to 0.5 of a pH unit lower. Total organic carbon contents were highest (14.8%) in the 5Oijg horizon (95 to 110 cm). Total organic C was also elevated at the surface and measured 3.3%. Total sulfur measurements increased with depth and ranged from 0.1% at the surface layer to a maximum of 11.3% in horizon 5Oijg (Figure 6-5). Carbonate content was highest at the near surface layers, measuring 1.5% $CaCO_3$, and was not detected in the underlying layers.

Table 6-4 Summary of soil morphology for profile BG 15: *Moist (winter) moderately well drained, open low scrub and grasses.* Soil colour was determined on moist samples and consistence was determined 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 15-188)	0-5	Brown to greyish brown (10YR3/2) silty loam without mottles; moderate coarse subangular blocky structure; strong consistency; some fine roots; gradual and diffuse boundary	
A (BG 15-189)	5-15	Greyish brown (10YR4/2) clay loam with common fine, very faint, yellow (10YR7/8) mottles penetrating peds; strong subangular blocky structure; strong consistency; few fine roots; diffuse boundary	
E (BG 15-190)	15-25	Pale yellow (5Y7/3) silty clay with strong brown (7.5YR5/6) mottles (10% volume) impregnating matrix of peds. Strong, subangular blocky structure; very few living roots, diffuse boundary	
2Ey1 (BG 15-191)	25-30	Pale yellow (5Y7/3) silty clay with strong brown (7.5YR5/6) mottles (15% volume) impregnating matrix of peds. Strong, subangular blocky structure; very few living roots, diffuse boundary. Few gypsum crystals	
2Ey2 (BG 15-192)	30-40	Pale yellow (5Y7/3) silty clay with strong brown (7.5YR5/6) mottles (20% volume) impregnating matrix of peds. Strong, subangular blocky structure; very few living roots, diffuse boundary. Some gypsum crystals	
3Bty (BG 15-193)	40-65	Greyish brown (10YR5/2) medium sandy clay with few brown (7.5YR5/4) mottles of Fe-ox coating or infilling root channels (mangrove pneumatophores and seagrass); weak, medium subangular blocky structure; very few living roots, graded, sharp boundary	
4Bjy (BG 15-194)	65-95	Dark greyish brown (10YR3/2) clayey peat with many pale brown (10YR6/3) mottles (25% 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; no living roots, common dead roots; sharp and smooth boundary	
5Oijg (BG 15-250)	95-110	Dark greyish brown (10YR3/2) organic sandy peat with many pale brown (10YR6/3) mottles (20% volume) of jarosite impregnating matrix; weak; layered mat structure (dominated seagrass fragments); non calcareous; no living roots; sharp and smooth boundary	
6Bijg/W1 (BG 15-196)	110-120	Light brownish grey (10YR6/2) medium sand with prominent light brownish grey (2.5Y6/2) jarosite mottles (5% volume) along root channels and seagrass fibres up to 5 mm thick; sand texture; weak single grain structure; non calcareous; no roots; diffuse boundary	
6Bg/W2 (BG 15-251	120-150	Dark greyish brown (10YR4/2) medium sand with no mottles; weak single grain structure; non calcareous; no roots and diffuse boundary	
7Bg/W1 (BG 15-252)	150-170	Dark greyish brown (10YR4/2) (gleyed) sandy clay no mottles; strong blocky structure; non calcareous; no roots	

Soil profile BG 15 classifies as: Typic Sulfaquepts (Soil Survey Staff 2010); Sulfuric Salic Hydrosol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil-water pH (pH_W) values (Figure 6-5) for near surface soil layers (i.e. horizons Oe, A, E) are circum-neutral. Soil layer 2Ey1 (between 25 and 30 cm depth) is slightly acidic with a pH_W of 4.3. Soil layers between 30 and 150 cm were acidic with pH_W ranging between 1.5 and 3.5. The pH_W of the soil layer below 150 cm depth (7Bg/W1) was less acidic, with a pH_W of 4.7 (Figure 6-5).Peroxide oxidation tests (pH_{OX}) were performed on all samples to gauge the likely presence of sulfidic materials. Although the pH of most soil samples dropped by more than 1 pH unit following treatment with hydrogen peroxide, only one non-sulfuric soil sample experienced a drop in pH to less than 2.5 (Figure 6-5). After incubating soil samples for at least 19 weeks, only one sample (from layer 7Bg/W1) showed a drop in pH of at least 0.5 pH unit to less than pH 4, which is likely due to sulfide oxidation, according to pH_{OX} and S_{CR} analysis data.

Existing Acidity (Titratable actual acidity (TAA) and Retained acidity)

All 8 samples analysed had a pH_{KCl} of < 6.5, indicating they contain Existing Acidity as TAA, which ranged between 15 and 468 mole H^+/tonne of soil (mean of 132 mole H^+/tonne). The highest TAA value occurred in organic matter rich soil layer 5Oijg (Figure 6-5). Retained acidity for the profile was very high, with a mean of 317 mole H^+/tonne. The highest retained acidity (1169 mole H^+/tonne) was measured in soil layer 4Bjy, which occurs between 65 and 95 cm depth.

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was determined on 8 samples within soil profile BG 15 and ranged between 0.01% and 6.88% indicating that the profile contains substantial Potential Sulfidic Acidity. The highest S_{CR} value was contained in the middle of the soil profile within a sandy peat soil layer (5Oijg) which also contained the highest TAA (Figure 6-5). No samples were analysed for AVS as no black mottles were observed.

Acid Neutralising Capacity (ANC)

All samples had a pH_{KCl} below 6.5 which by definition indicates that they contained zero effective ANC.

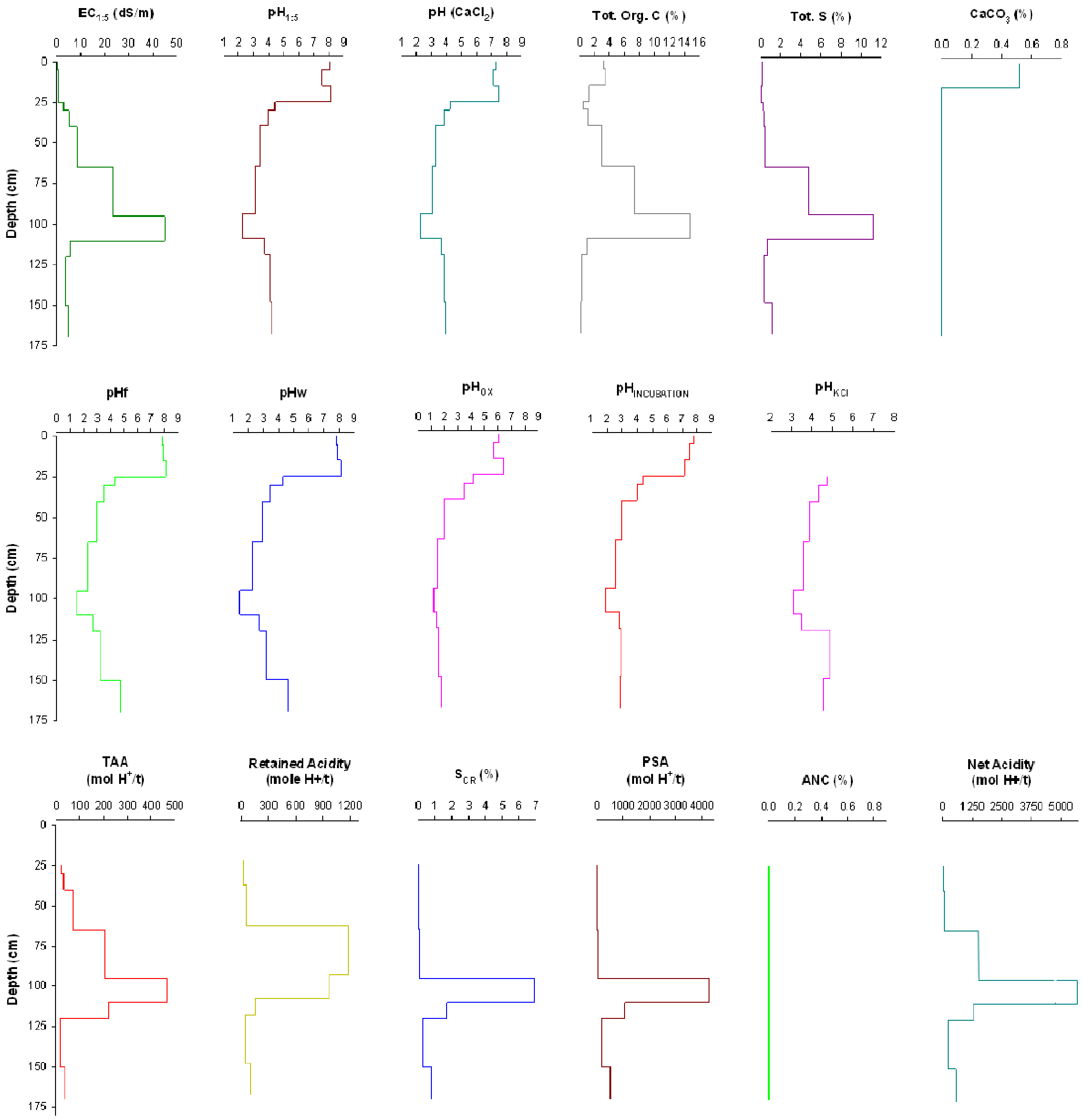


Figure 6-5 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 15.

Net Acidity

Net Acidity values were positive for all soil layers and range between 44 near the top of the profile and 5723 mole H^+/tonne in soil layer 5Oijg (65 to 95 cm). The majority of soil layers within profile BG 15 had high net acidity values, with a mean of 1218 mole H^+/tonne (Figure 6-5). The net acidity of the soil horizon 5Oijg equates to 9.18% S_{CR}, indicating that only one third of the PSA had oxidised in this layer.

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG 15 classifies as an acid sulfate soil, containing sulfuric material and hypersulfidic material.

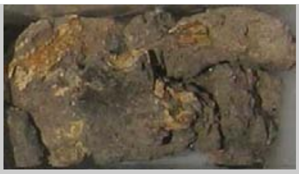
Map unit 3 - Wet (winter): poorly drained, open depression –bare salt scalded mud flats. Profile BG 17

Soil profile BG 17 occurs within map unit 3 (Bare salt scalded mud flat). Soil morphology for profile BG 17 is provided in Table 6-5 together with corresponding close-up photographs of soil fragments. Profile BG 17 originally developed in an intertidal regime but tidal sulfidic materials oxidised following tidal exclusion. The parent material consists of layers of tidal sediments deposited under mangrove vegetation.

The surface horizon (AE) was moist (due to wicking from shallow groundwater), poorly drained, sandy loam with well developed crumb structure (Table 6-5). Light yellowish brown jarosite mottles were evident in B horizons between 10 and 60 cms and occurred predominantly along larger pores (remnant from mangrove pneumatophores). Gleyed, dark grey sandy soil layers occur below 60 cm to 120 cm depth and contain some black mottles within the sandy matrix.

Soil EC was 12.2 dS/m in the surface layer due to salt crust formation and decreased with depth until the water table was approached, where soil layer 3Bjg1 was most saline (EC measured 38.0 dS/m). Soil pH (1:5) was acidic for the entire profile and ranged from 4.7 at the surface to a minimum of 2.9 at 40 cm depth (Figure 6-6). Soil pH_{CaCl_2} results were very similar to pH (1:5) values, but were about 0.1 to 0.5 of a pH unit lower. Total organic carbon contents were highest (7.7%) in the 3Bg/W2 horizon (60 to 100 cm). Total organic C was not elevated at the near surface and measured 0.9%. Total sulfur measured 0.3% at the surface and increased with depth to the water table where a maximum value of 4.6% was measured in horizon 3Bg/W2 (Figure 6-6). Carbonate was only detected in the 4Bg/W1 horizon at the base of the profile (measuring 1.0% $CaCO_3$).

Table 6-5 Summary of soil morphology for profile BG 17: *Moist, poorly drained, bare salt scalded mud flat.* Soil colour was determined on moist samples and consistence was determined on dry samples. Photos are of dried bulk samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (frame size: 5 x 2.5 cm)
AE (BG 17-236)	0-10	Very dark greyish brown (10YR3/2) sandy loam with some dark yellowish brown (10YR4/4) mottles; friable structure; weak consistency without coarse fragments; abundant fine roots; gradual and smooth boundary	
2Bjg1 (BG 17-238)	10-25	Dark greyish brown (10YR4/2) sandy loam some diffuse light yellowish brown (2.5Y6/4) mottles (5%:volume) penetrating peds; weak consistency without coarse fragments; no roots; diffuse wavy boundary	
2Bjg2 (BG 17-239)	25-40	Dark greyish brown (10YR4/2) loamy sand with common prominent light yellowish brown (2.5Y6/4) mottles (20%:volume) penetrating peds; weak consistency without coarse fragments; no roots; diffuse wavy boundary	
3Bjg1 (BG 17-240)	40-60	Very dark greyish brown (10YR3/2) loamy sand with common prominent light yellowish brown (2.5Y6/4) mottles (20%:volume) penetrating peds and forming along macropores up to 5 mm thick (mangrove pneumatophores) and organic matter and some distinct dark brown (7.5YR4/4) mottles of Fe-ox in the centre of root channels; weak consistency without coarse fragments; no roots; diffuse wavy boundary	
3Bg/W2 (BG 17-241)	60-100	Very dark grey (10YR3/1) medium organic rich sand with no mottles; weak single grain structure; non calcareous; no roots; gradual and smooth boundary	
4Bg/W1 (BG 17-242)	100-120	Dark greyish brown (10YR4/2) medium sand with no mottles; weak single grain structure; non calcareous; no roots	

Soil profile BG 17 classifies as: Salidic Sulfaquepts (Soil Survey Staff 2010); Sulfuric Salic Hydrosol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil-water pH (pH_W) indicated all soil layers were acidic, ranging from 2.4 to 3.4 (mean pH_W of 2.5) (Figure 6-6). The pH_{OX} results suggest that although the samples are already acidic, one soil sample contains enough sulfidic material to further significantly drop the pH (Figure 6-6). After incubating soil samples for at least 19 weeks, only the surface sample showed a further drop in pH. The vast majority of samples showed a slight rise in pH of between 0.5 and 1 pH unit. The pH of soil horizon 4Bg/W1 (the deepest layer) rose substantially following incubation, from pHw 3.06 to $pH_{Incubation}$ 4.74. This rise may be attributed to incubation samples being too moist, allowing reformation of sulfides to occur, and/or the soil carbonate present to react.

Existing acidity (Titratable actual acidity (TAA) and Retained acidity)

All six samples analysed had a pH_{KCl} of <6.5 (Figure 6-6), indicating they contain Existing Acidity as TAA, which ranged between zero (in the surface layer) and 140 mole H^+/tonne of soil in the 3Bjg1 layer (at 40 to 60 cm depth). The mean TAA value was 38 mole H^+/tonne) (Figure 6-6). Retained acidity was measured on all 6 samples and ranged between 87 mole H^+/tonne at the base of the profile to 524 mole H^+/tonne in the 2Bjg2 layer (25 to 40 cm depth) (Figure 6-6). The mean retained acidity value for the profile was 240 mole H^+/tonne.

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was detected in all 6 horizons sampled indicating that they all contain potential sulfidic acidity. S_{CR} values ranged form 0.01% for the two upper soil layers to 4.41% S_{CR} in a gleyed, very dark grey sandy soil layer 3Bg/W2 (from 60 to 100 cm). The profile had a mean S_{CR} value of 1.22%. The bottom three soil horizons were analysed for AVS due to the presence of dark grey to black mottles. AVS contents were low and ranged from 0.01 to 0.03% AVS (Figure 6-6).

Acid Neutralising Capacity (ANC)

All samples had a pH_{KCl} below 6.5 (Figure 6-6) indicating they contain zero effective ANC.

Net Acidity

Net Acidity values were positive for all soil layers assessed and range between 110 mole H^+/tonne at the surface to 2798 mole H^+/tonne at between 60 and 100 cm depth. The soil layer above (40 to 60 cm depth) had a similarly elevated net acidity of 2056 mole H^+/tonne. The mean net acidity value for profile BG 17 was 1037 mole H^+/tonne. The majority of the acidity in profile BG 17 is in the form of Potential Sulfidic Acidity (Figure 6-6).

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG 17 classifies as an acid sulfate soil, containing; sulfuric material, hypersulfidic material and monosulfidic material.

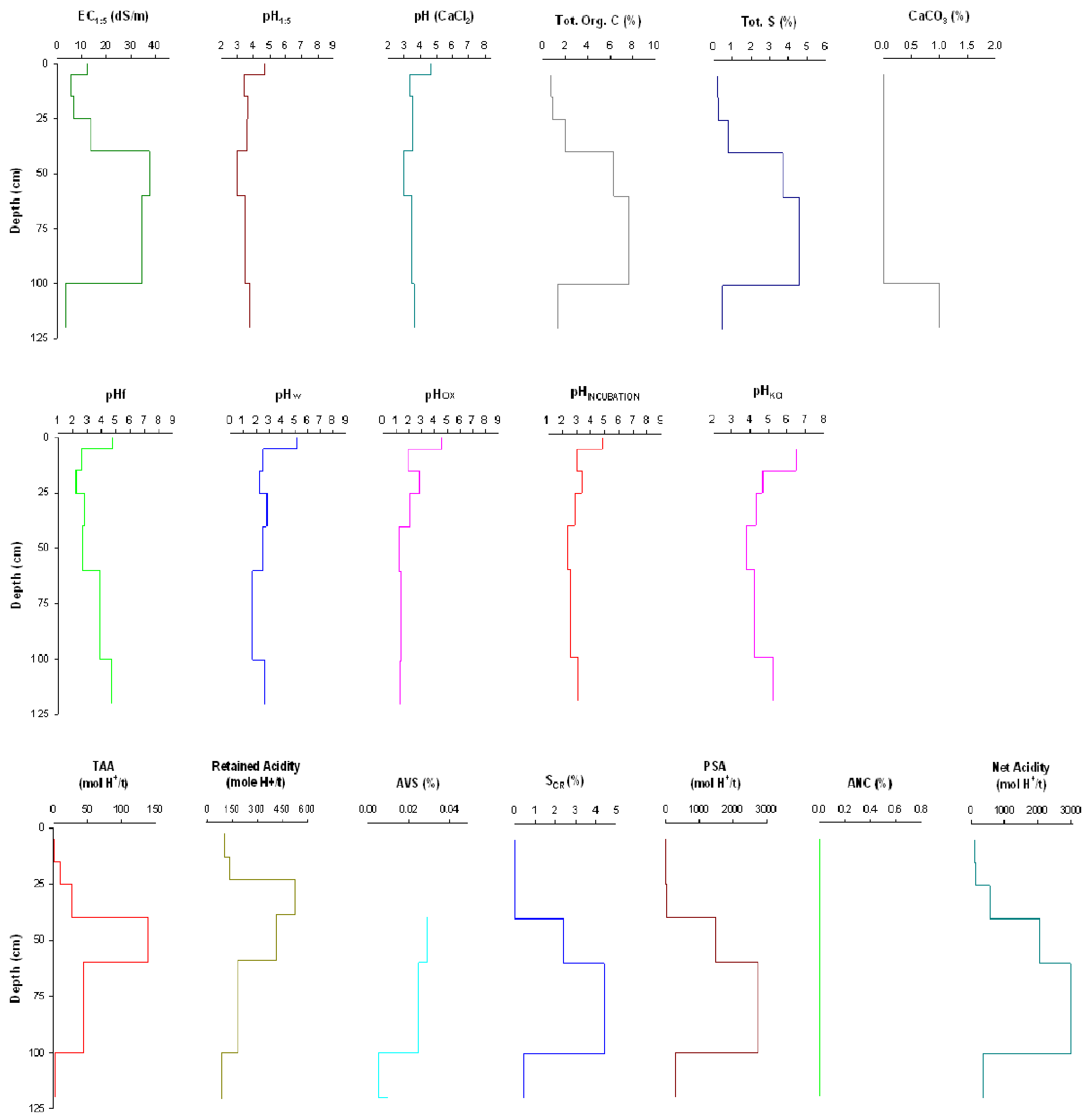


Figure 6-6 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 17.

Map unit 1 - *Wet (subaqueous): poorly drained, erosional channel – water. Profile BG P 5*

Soil profile BG P 5 occurs within map unit 1 (Water). Soil morphology for profile BG P 5 is provided in Table 6-6 together with a corresponding close-up photograph of soil fragments from each horizon. Profile BG P 5 originally developed in an intertidal to supratidal regime. Profile BG P 5 occurs in a pond that was excavated during the construction of the Range Wetland in 1992 and has since been filled with saline water (Figure 6-1). The black surface Oa/W1 and Ag/W1 horizons (from 0 to 10 cm) comprises wet, organic matter rich, light clay with a gel-like or ooze consistency. The black colour and ooze-like consistency is a good indicator of strongly reduced redoximorphic conditions and indicates the likely presence of monosulfidic material (i.e. AVS). Underlying B horizons (from 10 to 60 cm) consist of gleyed, dark olive grey clays with abundant black mottles. Clay content increased with depth.

Table 6-6 Summary of soil morphology for profile BG P 5: *Wet, saturated (subaqueous) soil in saline groundwater discharge pond.* Soil colour was determined on moist samples and consistence was determined on dry samples. Photos are of **moist** bulk samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (frame size: 5 x 2.5 cm)
Oa/W1 (BG P 5-310)	0-5	Black (5Y2.5/1) without mottles; massive structure; weak (gel-like when wet) consistency without coarse fragments; no roots; gradual and smooth boundary	
Ag/W1 (BG P 5-307)	5-10	Very dark grey (5Y3/1) without mottles; massive structure; weak (gel-like when wet) consistency without coarse fragments; no roots; gradual and diffuse boundary	
2Bg/W1 (BG P 5-308)	10-25	Dark olive grey (5Y3/2) medium clay without mottles; massive structure; weak consistency without coarse fragments; non calcareous; no roots; diffuse boundary	
3Bg/W1 (BG P 5-309)	25-60	Olive grey (5Y4/2) heavy clay with some pale olive (5Y6/4) mottles (10% volume); massive structure; firm consistency without coarse fragments; non calcareous; no roots	

Soil profile BG P 5 classifies as: Typic Hydrowassents (Soil Survey Staff 2010) and a Sodosolic Salic Hydrosol (Isbell 2002).

Soil EC was reasonably consistent throughout the profile and ranged from 6.7 to 5.1 dS/m. Soil pH (1:5) was near neutral for the entire profile and ranged from 7.0 in the lower 3Bg/W1 horizon (25 to 60 cm) to 7.5 in the surface Oa/W1 horizon (0 to 5 cm). Soil pH_{CaCl_2} results were very similar to pH (1:5) values, but were about 0.2 to 0.3 of a pH unit lower. Total organic carbon contents were moderately low and ranged from 1.2% in the Ag/W1 horizon (5 to 10 cm) to 2.1% in the surface Oa/W1 horizon, with a mean of 1.7% for the profile. Total sulfur measurements were surprisingly low, measuring 0.1% in the surface Oa/W1 horizon, 0.6% in the lower Ag/W1 horizon, and 0.1% in underlying B horizons (Figure 6-7). Carbonate content was highest in the near surface Ag/W1 horizon (2.4% $CaCO_3$).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil:water pH measurements were made in a 1:1 soil-water mixture (pH_W), after treatment with peroxide (pH_{OX}) and after 19 weeks of ageing ($pH_{Incubation}$) the soil in a moist environment. Soil-water pH data show that all soil layers were circum-neutral (Figure 6-7). A drop in pH was observed for most samples following treatment with peroxide, however only two soil sample (from horizons Ag/W1 and 3Bg/W1) contained sufficient sulfidic material to obtain a pH_{OX} of less than 2.5 (Figure 6-7). After incubating soil samples for 19 weeks the pH of all soil layers remained above pH 4. All samples showed a slight drop in pH of between 0.5 and 1 pH unit during incubation.

Existing acidity (Titratable actual acidity (TAA) and Retained acidity)

All four samples analysed had a pH_{KCl} of >6.5 (ranging from pH_{KCl} 8.02 to 8.83), indicating they contain no Existing Acidity.

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was determined for 4 layer samples within soil profile BG P 5. S_{CR} values ranged form 0.99% in the surficial black gel to 0.19% in the underlying soil layer. All samples were analysed for AVS content, which had a very similar down profile distribution pattern as the S_{CR}. AVS contents ranged from 1.14% in the surficial black gel to 0.08% in the gleyed olive grey clay at the base of the soil profile (Figure 6-7).

Acid Neutralising Capacity (ANC)

Effective ANC values ranged between 0.7% $CaCO_3$ and 1.45% $CaCO_3$, with the highest value occurring in the near surface Ag/W1 (5 to 10 cm) soil layer.

Net Acidity

Net Acidity values range from -78 mole H^+/tonne in the near surface Ag/W1 soil layer (5 to 10 cm) to 456 mole H^+/tonne at the surface Oa/W1 horizon (0 to 5 cm) (Figure 6-7).

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG P 5 classifies as an acid sulfate soil, containing both hyposulfidic and monosulfidic materials.

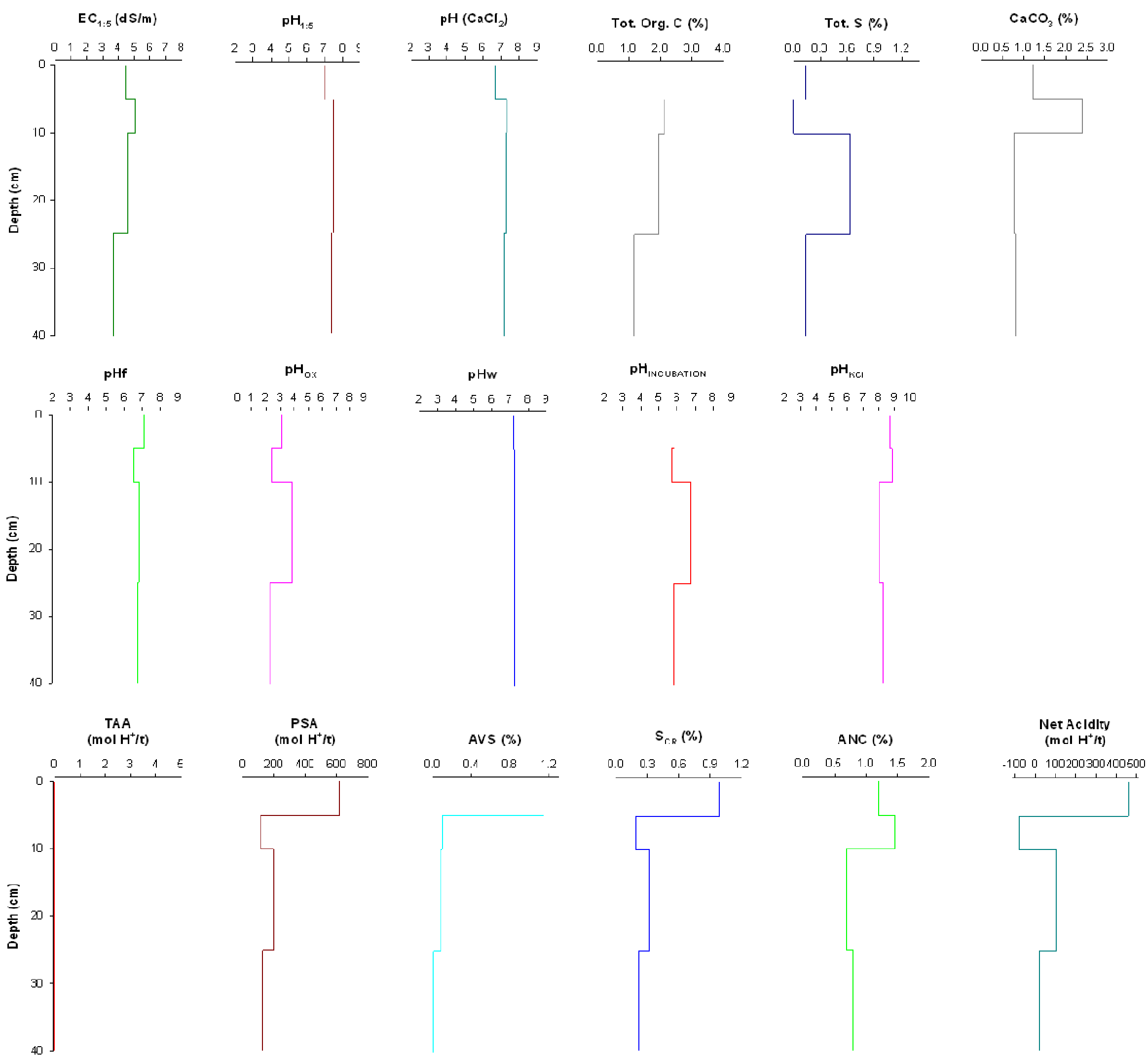


Figure 6-7 Down profile soil chemistry and acid sulfate soil characteristics of profile BG P 5.

Summary - Gillman Focus area A

Soil profiles BG 11 (map unit 6) and BG 15 (map unit 5) both classify as Sulfuric, Salic Hydrosols (Isbell 2002) and Typic Sulfaquepts (Soil Survey Staff 2010). These two profiles are dominated by sandy shore face sediments that underlay organic matter rich intertidal mangrove loams and supratidal samphire clays of varying thickness. Soil profile BG 11 contains a thick layer of sulfuric material between 49 and 240 cm depth, with hypersulfidic and hyposulfidic materials occurring below 240 cm. Sulfuric materials also contain some reduced inorganic sulfide. Soil profile BG 15 contains a thick layer of sulfuric material, between 30 and 160 cm depth, with hypersulfidic material occurring below 160 cm. Sulfuric material contained high amounts of existing acidity and extremely high PSA, with reduced inorganic sulfide contents of up to 6.88% S_{CR} remaining in the profile.

Soil profile BG 17 (map unit 3) classifies as a Sulfuric Salic Hydrosol (Isbell 2002) and Salidic Sulfaquepts (Soil Survey Staff 2010), and contains sulfuric material from the surface to below 120 cm depth. Sulfuric material also contains high concentrations of reduced inorganic sulfur contents (up to 4.4%) and minor amounts of AVS in black mottles that occur below the water table.

Subaqueous soil profile BG P 5 (map unit 1) classifies as a Sodosolic Salic Hydrosol (Isbell 2002), and a Typic Hydrowassents (Soil Survey Staff 2010). Soil profile BG P 5 contains hyposulfidic material and monosulfidic material (with up to 1.14% AVS) in near surface layers.

The very high S_{CR} levels measured in profile BG 15 may be natural (historically high in the back barrier formation sediments). However nutrient rich, hypersaline water from the Range Wetland is probably contributing to local groundwater recharge and providing constituents for the formation of FeS and FeS_2 in saturated soils. Soil profile BG 4 in Gillman Focus area B has similarly elevated S_{CR} values (maximum of 7.05%) and is also influenced by hypersaline waters (refer to the next section in this chapter and Appendix B).

Profiles in map unit 6 contained much lower existing acidity and potential sulfidic acidity than profiles from map unit 5 (Table 6-7). This may be due to the topographically higher, sandy profiles of map unit 6 being more extensively oxidised and leached. Partial oxidation of the more prominent (formerly supratidal) areas at Gillman may pre-date construction of the bund walls and be related to the geomorphic history of the area. The coastal sand barrier that dominates map unit 6 at Gillman has been dated at 6600 BP (Bowman and Harvey 1986). Oxidation soils in map unit 6 may have begun with the stabilisation of sea levels that subsequently followed. Therefore the movement of oxidation products to lower positions in the landscape may be partially responsible for the extreme S_{CR} contents observed in soil of map unit 5.

Table 6-7 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 depth, including an AVS content of 0.03%
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%

6.1.2. Gillman Focus area B

Focus area B is sited at a former tidal creek that forms a subtle erosion gully in the geomorphically-controlled, relic sandy shore face facies (Figure 6-1). The sandy shore face facies forms a north-east projecting ridgeline (topographic high). The ridgeline and tidal creek depression are evident in aerial photography and on the digital elevation map (Figure 3-6). Prior to the construction of the bund walls in 1935 the sandy ridgeline was supratidal and covered by samphire vegetation (Belperio and Rice 1989).

Focus Area B encompasses two soil profiles located on a northeast trending toposequence that traverses from a relatively high sand ridge (profile BG 5) to a lower lying, seasonally inundated creek channel (profile BG 4) (Figure 6-8). Soil profile BG 4 is representative of map unit 2 (Benthic mat and bare salt scalded mud flats) while soil profile BG 5 is representative of map unit 6 (Open grass plain and scrub) (refer to Table 6-8 and Figure 6-9).

Table 6-8 Soil profiles selected to be representative of map units occurring within focus area B, and along toposequence transect B-B' in Figure 6-8 and Figure 6-9.

Soil profile numbers	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Disturbed intertidal to supratidal areas (Gillman study site)				
BG 4	0.6 m AHD	**2.** Benthic mat and bare salt scalded mud flats	Erosional channel stranded tidal creek channel	Wet (winter), poorly drained –seasonally inundated > 2 cm (and following storm event)
BG 5	2.1 m AHD	**6.** Open grass plain and scrub	Open flat plain – upper former intertidal floodplain	Moist (winter), well drained

A summary description of these profiles is provided in this section. Detailed morphological descriptions and soil chemical data are provided in Appendix B.

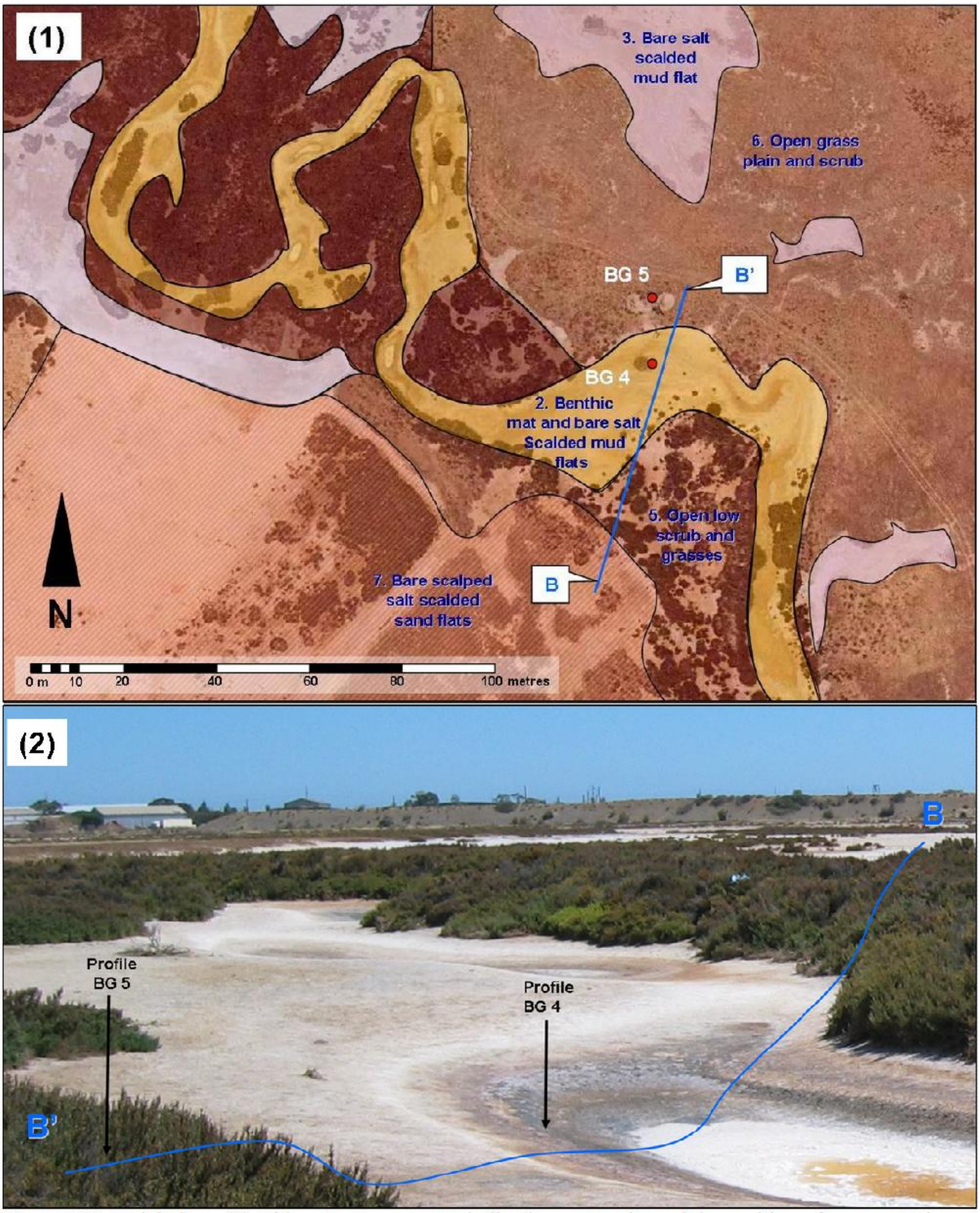


Figure 6-8 Aerial photo (1) with a transparent map indicating map units and the position of representative soil profiles BG 5 within map unit 6 (Open grass plain and scrub) and soil profile BG 4 within map unit 2 (Benthic mat and bare salt scalded mud flats). Landscape photo (2) shows the position of the soil profiles along toposequence transect B-B'.

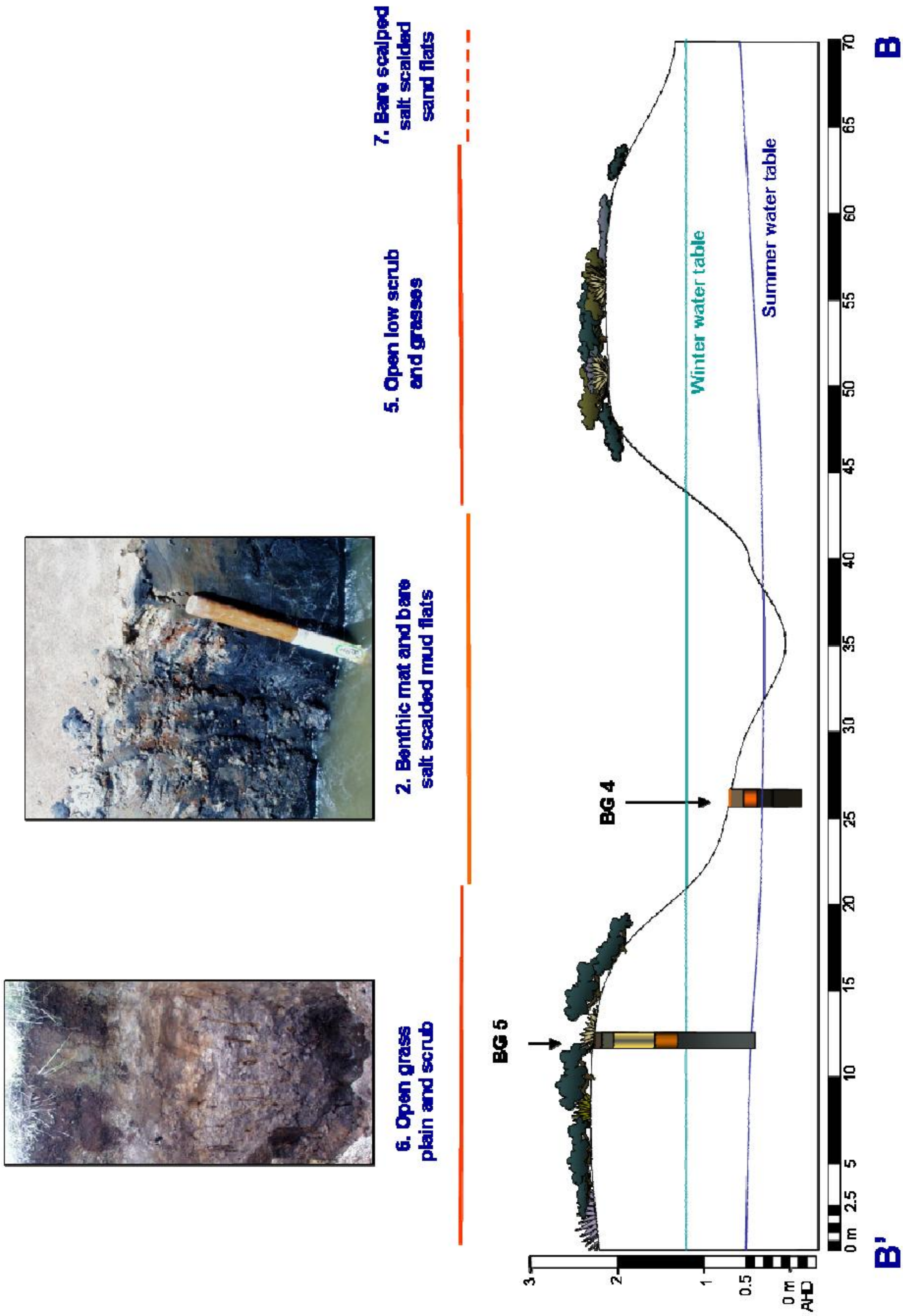


Figure 6-9 Descriptive soil-regolith toposequence model (cross section B-B' shown in Figure 6-8) indicating map units, position of representative soil profiles with colour photographs and average water table depth. Refer to Appendix B for descriptions of the soil profiles.

Summary - Gillman Focus area B

Toposequence B-B' traverses from elevated sandy shore face facies sediments (profile BG 5) to low lying sandy tidal creek sediments (soil profile BG 4) (Figure 6-8 and Figure 6-9). These two profiles have different physical features (e.g. water state and redox conditions), which are reflected by their chemical and acid sulfate soil characteristics. The profiles share characteristics to other soils that occur in the same map unit counterparts. Profile BG 5 is similar to BG 11, being relatively leached of salts and sulfur and containing sulfuric materials above the redox boundary (Appendix B).

Minor residual, reduced inorganic sulfur remains in the oxidised zone but S_{CR} contents are much higher below the redox boundary in gleyed soils horizons. Some topographical edge effect would probably have contributed to the leaching of profile BG 5, which is positioned on the bank of the creek depression (Figure 6-9). This topographically controlled leaching (edge) effect is evident on aerial photographs by a sharp contrast in vegetation (surface cover type) along the banks of creek depressions (Figure 6-1).

The creek depression in which profile BG 4 is located is inundated seasonally, or following substantial storms events. When profile BG 4 is inundated for extended periods it resembles the subaqueous soil profile BG P 5 (map unit 1); with black, gel-like near surface layers. During summer subsoil layers in profile BG 4 retain very high AVS contents (up to 3.5%), and high reduced inorganic sulfur contents (up to 7.1%) (Appendix B). During dry months the near surface layers (top 10 to 20 cm) of profile BG 4 are partially oxidised and become acidic with pH <4 (Appendix B). Soil horizons containing monosulfidic material have also accumulated carbonate/bicarbonate (of about 7% $CaCO_3$).

Profile BG 4 had similarly high S_{CR} and net acidity contents in subsoil layers to the sandy soil profile BG 17 (map unit 3).

Profile BG 4 classifies as Sulfuric Hypersalic Hydrosol*(Isbell 2002), Salidic Sulfaquepts (Soil Survey Staff 2010) containing; both hypersulfidic and hyposulfidic materials and monosulfidic materials (Table 6-9).

Profile BG 5 classifies as a Sulfuric Salic Hydrosol (Isbell 2002) and Typic Sulfaquepts (Soil Survey Staff 2010) containing; sulfuric material and both hypersulfidic and hyposulfidic materials (Table 6-9).

Refer to Appendix B for detailed morphological descriptions of these two soil profiles, including photographs of soil samples and plotted soil chemical data.

Table 6-9 Gillman 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 number	**Map unit no.**	**Aust. Soil Classification (Isbell 2002)**	**Soil Taxonomy (Soil Survey Staff 2010)**	**Acid Sulfate Soil materials**	**Significant net acidity occurrence**
BG 5	**6.** Open grass plain and scrub	Sulfuric Hypersalic Hydrosol*	Salidic Sulfaquepts	Sulfuric material, hypersulfidic and hyposulfidic materials	160 cm @ 115 mole H^+/t from 30 cm depth
BG 4	**2.** Benthic mat and bare salt scalded mud flats	Sulfuric Salic Hydrosol	Typic Sulfaquepts	Hypersulfidic material, hyposulfidic and monosulfidic materials	35 cm @ 2785 mole H^+/t from 30 cm depth, including an AVS content of 3.5%

*Proposed New Great group for (Isbell 2002).

6.1.3. Gillman Focus area C

Focus area C is situated at the northern end of Gillman and covers the undrained (intertidal) and drained (formerly intertidal) zones on either side of the bund wall (Figure 6-10 and Figure 6-11). The undisturbed area to the north of the bund wall is covered by thick intertidal samphire and mangrove vegetation that is generally flooded each day. This section of the bund wall was constructed in 1935. The drained part of Focus area C was formerly covered by intertidal samphire and mangrove vegetation.

The southern section of Focus area C is characterised by a low-lying, stranded tidal creek that forms a lake (ponding basin) during wet winter months. The lake is fed by stormwater overflow from the Range Wetlands (at Focus area A; Figure 6-1). The majority of the lake dries out during summer, with a small body of water remaining at the bund wall which acts as a dam. Soil profile BG 30 was located at this area of permanent water (Figure 6-11).

Focus Area C encompasses **eight soil profiles** located on a 550 m long, north-south trending toposequence. The toposequence C’-C traverses across the bund wall from tidal samphire and mangrove vegetation to drained samphire vegetation and across relatively low lying seasonally and permanently inundated creek channel soils (Figure 6-11).

The tidal zone contains map units 9 (Water), 10 (Mangrove woodlands) and 11 (Low growing salt marsh plants), that are represented by soil profiles BG 24, BG 21 and BG 20 respectively (Table 6-10).

Four map units occur on the southern (drained) side of the bund wall and include 1 (Water), 2 (Benthic mat and bare salt scalded mud flats), 3 (Bare salt scalded mud flats) and 4 (Dense low heath-samphire shrublands). These map units are represented by soil profiles BG 30, BG 28, BG 32 and BG 22 respectively (refer to Figure 6-10 and Table 6-10).

In this section full profile descriptions are provided for soil profiles BG 28 and BG 22 to represent map units 2 and 4. Characteristics of the remaining 6 soil profiles that occur on toposequence C’-C are summarised in the discussion below and comparisons are made to soil profiles occurring within equivalent map units from other focus areas. Detailed morphological descriptions of these six soil profiles, including photographs of soil samples and plotted soil chemical data, are provided in Appendix B.

Table 6-10 Soil profiles selected to be representative of map units occurring within focus area C, and along toposequence transect C-C’ in Figure 6-10 and Figure 6-11.

Soil profile numbers	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Intertidal to supratidal areas (Gillman study site)				
BG 20	1.6 m AHD	**11.** Low growing salt marsh plants	Open flat – intertidal to supratidal zone	Wet, poorly to moderately well drained
BG 21	1.2 m AHD	**10.** Mangrove woodlands	Open flat – intertidal floodplain	Wet, moderately to poorly drained
BG 24	-0.1 m AHD	**9.** Water	Erosional channel - tidal creek channel	Wet, poorly drained
Disturbed intertidal to supratidal areas (Gillman study site)				
BG 28	0.8 m AHD	**2.** Benthic mat and bare salt scalded mud flats	Erosional channel stranded tidal creek channel	Wet (winter), poorly drained –seasonally inundated > 2 cm (and following storm event)
BG 22	1.2 m AHD	**4.** Dense low heath - samphire shrublands	Open flat plain – lower former intertidal floodplain	Moist (winter), moderately well drained
BG 32	0.8 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 31	0.5 m AHD	**2.** Benthic mat and bare salt scalded mud flats	Erosional channel stranded tidal creek channel	Wet (winter), poorly drained –seasonally inundated > 2 cm (and following storm event)
BG 30	-0.3 m AHD	**1.** Water	Erosional channel – stranded tidal creek channel	Wet, poorly drained – permanently inundated >5 cm, (subaqueous soils)

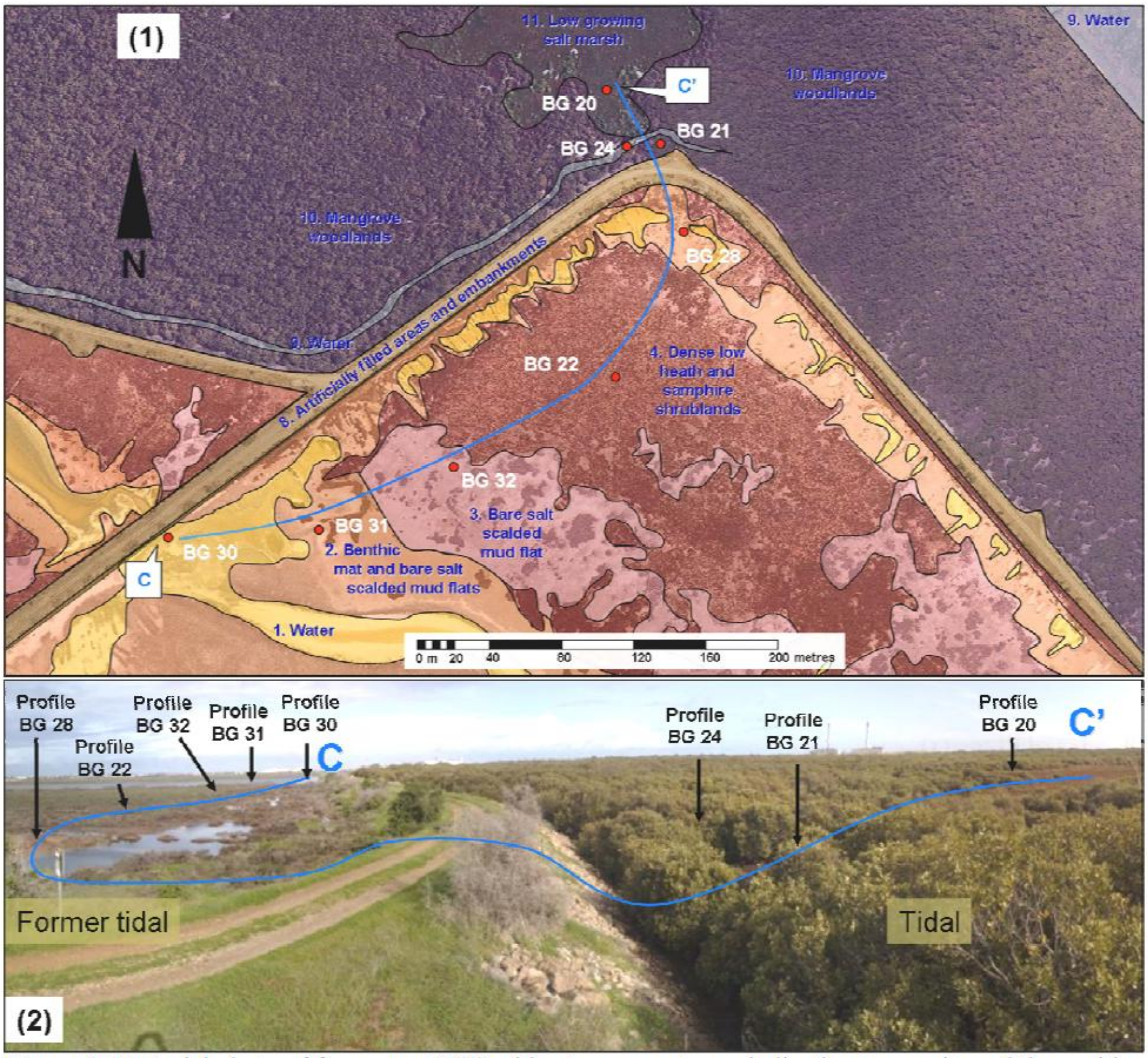


Figure 6-10 Aerial photo of focus area C (1) with a transparent map indicating map units and the position of representative soil profiles along transect C'-C, from an intertidal zone covered by thick samphire and mangrove vegetation to drained former intertidal and tidal areas on the southern side of the 3.5 m high bund wall, which was constructed in 1935. Landscape photo (2) shows the position of the soil profiles along toposequence transect C'-C.

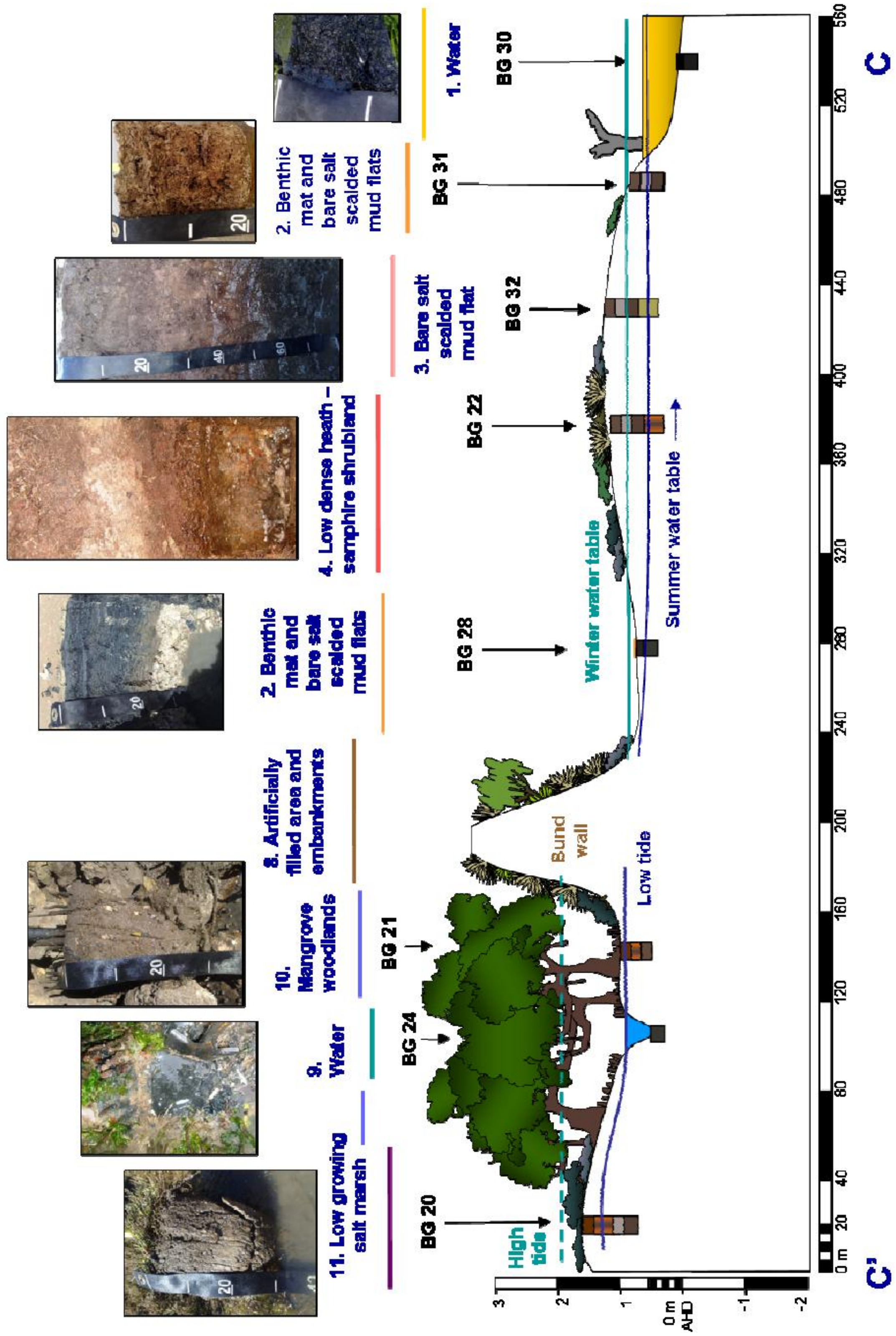


Figure 6-11 Descriptive soil-regolith toposequence model (cross section C-C' see Figure 6-10) indicating map units, position and photographs of representative soil profiles with colour photographs of each profile, average water table depth and groundwater flow direction. Full descriptions of profiles are provided in Table 6-11 (BG 28) and Table 6-12 (BG 22). Descriptions of all other profiles in Focus area C are provided in Appendix B.

Map unit 2 - *Wet (winter): poorly drained, seasonally inundated erosional channel – with a surface cover of benthic mat and bare salt scalded mud flats. Profile BG 28*

Soil profile BG 28 occurs within map unit 2 (Benthic mat and bare salt scalded mud flats). Soil morphology for profile BG 28 is provided in Table 6-11 together with corresponding close-up photographs of soil fragments from each soil horizon. The erosion gully / depression in which BG 28 is located was originally formed when topsoil was scalped for constructing the bund wall in 1935. A depression of about 20-40 cm depth runs parallel to the landward (southern) side of the bund wall and now forms a meandering drain during winter months (Figure 6-10). The parent material consists of several layers of tidal sediments deposited under mangrove and samphire vegetation.

The surface Az1 horizon was moist at the time of sampling due to recent rainfall and wicking of saline groundwater. The surface had a 1 cm thick fibrous benthic mat with pink salt crust that likely contained halite and gypsum (Table 6-11). The Ag2 horizon (1 to 20 cm) had a gleyed, predominantly black matrix (Table 6-11), which is likely due to monosulfides (Figure 6-11). The Ag3 horizon consists mainly of sandy clay containing some decomposed organic matter, and is underlain by a layer of olive grey, wet, clayey sand with abundant broken shell fragments (horizon 2Bg/W1).

The surface Az1 layer had an EC of 22 dS/m (1:5). The underlying A and B horizons had slightly lower EC values (Figure 6-11). Soil pH (1:5) was alkaline throughout the soil profile (measuring 9.2 at the surface and 8.3 at 40 cm depth). Soil pH_{CaCl_2} measurements were within 0.2 of a pH unit of soil pH (1:5) values. Organic carbon content was low at the surface (0.5%) and increased slightly with depth, measuring 1.2% at 40 cm depth. The surface horizons contained the highest total sulfur content (measuring 1.7% in the Ag2 horizon) and decreased with depth to 0.3% at the base of the profile (Figure 6-11). Carbonate content measured 8.8% at the near surface layers and 12.1% at the base of the profile in the 2Bg/W1 horizon, which contained abundant broken shells (Table 6-11). Horizon Ag3 (20 to 25 cm) contained 0.5% $CaCO_3$.

Table 6-11 Summary of soil morphology for profile BG 28: Moist (winter), poorly drained saline groundwater discharge pond. Soil colour was determined on moist samples and consistence was determined on dry samples. Photos are of **moist** samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Az1 (BG 28-328.1)	0-1	Very thin (1-2 mm), pale yellow (2.5Y7/3) fine sand surface at the surface with some fibrous organic matter (filamentous algae). Small halite and gypsum crystals evident just below the surface.	
Ag2 (BG 28-328.2)	1-20	Black (N 2.5/), medium sandy clay with minor grey (2.5Y5/1) mottles (2-5% volume); friable structure; weak consistency without coarse fragments; no roots	
Ag3 (BG 28-328.3)	20-25	Dark greyish brown (10YR4/2) highly organic loam (50% mineral, 50% hemic organic matter) with no live roots. No mottles; some medium grain sized broken shell fragments; gradual wavy boundary	
2Bg/W1	25-40	Olive grey (5Y4/2) clayey medium sand; slight H_2S smell; many medium to coarse broken shell fragments.	

Soil profile BG 28 classifies as: Typic Haloquepts (Soil Survey Staff 2010) and an Epicalcareous Hypersalic Hydrosol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil pH measurements were made on all four samples in a 1:1 soil-water mixture (pH_W), after treatment with peroxide (pH_{OX}) and after ageing the soil in a moist environment ($pH_{Incubation}$). Soil-water pH (pH_W) data show that soil layers are circum-neutral, ranging from 7.1 at the base the profile, where carbonate content is highest, to 7.5 in the near surface horizons. Peroxide pH tests (pH_{OX}) showed a slight drop in pH for all samples following oxidation, with the largest drop experienced by Ag3, which dropped 2.2 pH units to a pH_{OX} of 5.3 (Figure 6-12). The lowest soil $pH_{Incubation}$ of 6.4 was measured in horizon Ag3, after ageing for 19 weeks, supporting the pH_{OX} data. These results suggest that samples are likely to contain minor amounts of reduced inorganic sulfur, but are unlikely become acidic (pH < 4) if oxidised (Figure 6-12).

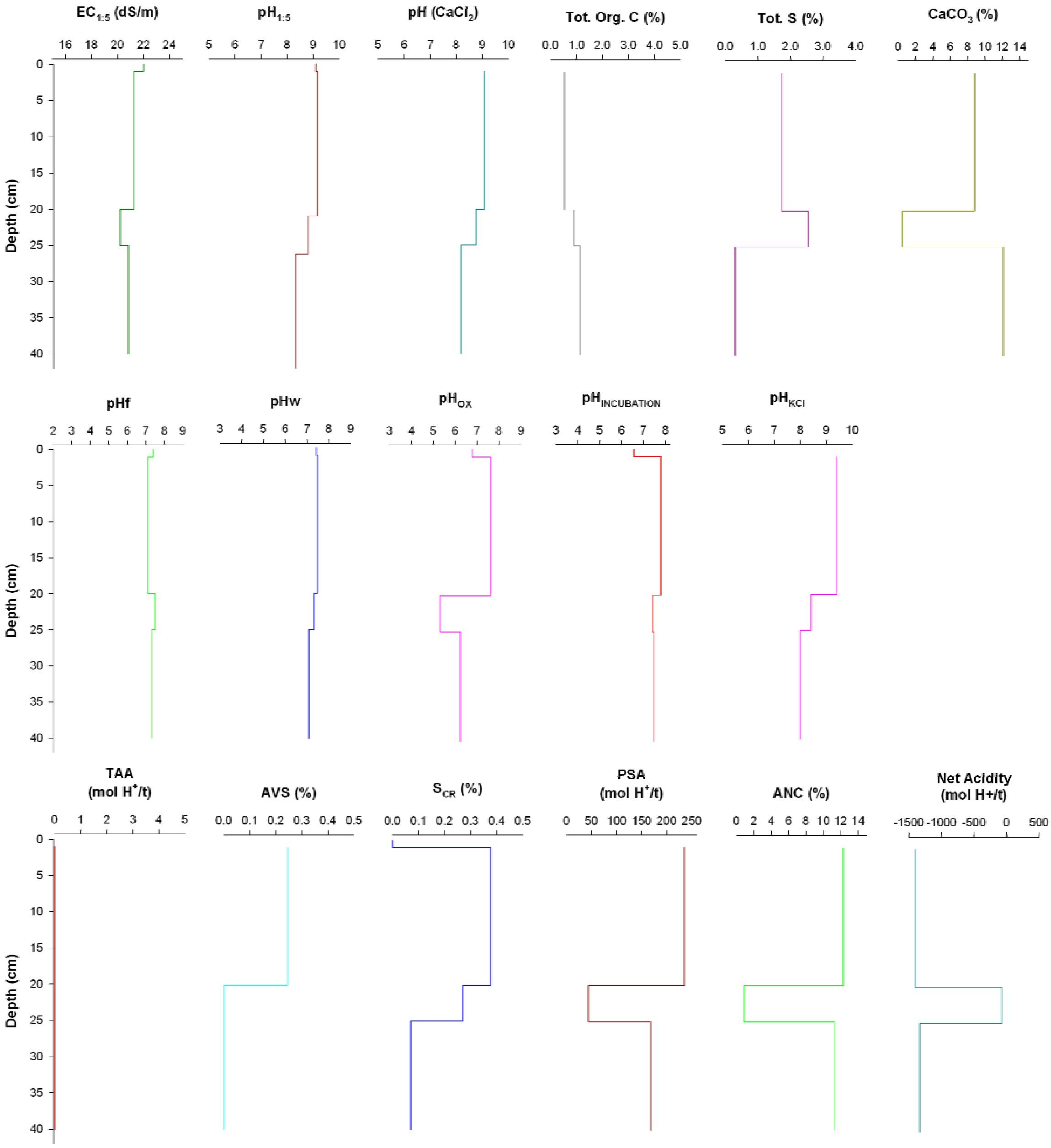


Figure 6-12 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 28.

Titratable actual acidity (TAA)

All of the three samples analysed had a pH_{KCl} of >6.5, indicating they do not contain Existing Acidity. TAA ranged between 9.4 at the top of the profile to 8.0 at the base. Retained acidity was not measured as all samples had a pH_{KCl} of >4.5 and no jarosite was observed in the samples.

Acid Volatile Sulfur

Acid volatile sulfur was determined for soil horizon Ag2 (1 to 20 cm) due to its black matrix colour, and measured 0.25% AVS.

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur values measured 0.38% in horizon Ag2, 0.27% in horizon Ag3 and 0.07% in the 2Bg/W1 horizon, indicating that these layers contained Potential Sulfidic Acidity (Figure 6-12).

Acid Neutralising Capacity (ANC)

Acid neutralising capacities were high (above 11%) in the near surface Ag2 horizon and lower 2Bg/W1 horizon. The Ag3 horizon had an ANC of 0.9%.

Net Acidity

Net Acidity values are negative for all soil layers assessed and range between -72 and -1326.5 mole H^+/tonne, with a mean of -937 mole H^+/tonne for the profile (Figure 6-12). This is to be expected with relatively high ANC values found in the soil.

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG 28 classifies as an acid sulfate soil, containing; hyposulfidic material and monosulfidic material.

Map unit 4 - ***Moist (winter): moderately well drained, open flat plain in the lower former intertidal floodplain with a surface cover of dense low heath and samphire shrublands. Profile BG 22*****.**

Soil profile BG 22 occurs within map unit 4 (Dense low heath and samphire shrublands). Soil morphology for profile BG 22 is provided in Table 6-12 together with a corresponding close-up photograph of soil fragments from each horizon. Profile BG 22 developed in an intertidal regime prior to construction of the bund wall. The soil material consisted of an organic rich sandy loam layer (25 cm thick) that formed under samphire and mangrove vegetation. A shell grit layer (buried chenier ridge) occurred below 40 cm.

The near surface horizon (Oe1; 0-5 cm) consisted of a moderately well drained, friable, organic rich fine sandy loam with some live and dead roots, and no redoximorphic features. The underlying Oe2 horizon (5-15 cm) had a slightly higher mineral content and was finely layered. Some strong brown mottles occurred along root channels. The underlying Oe3 horizon (15-25 cm) had a subangular blocky structure with a slightly stronger consistency and some strong brown mottles (about 5% volume).

Two B horizons occur below the organic rich O horizons; 2Bw (25 to 40 cm) and 3Bg/W1 (40 to 65 cm). The 2Bw horizon consisted of greyish brown, medium loamy sand (non-calcareous), with minor yellowish red mottling along fine root channels and ped surfaces. The underlying 3Bg/W1 horizon was a gleyed, olive grey, medium sandy clay with minor yellowish red mottles distributed through the matrix and along broken shell surfaces (Table 6-12).

The surface Oe1 and Oe2 horizons had relatively low ECs of 8.6 and 8.7 dS/m (Figure 6-13). The three underlying layers had much higher ECs of 34.2, 27.1 and 22.1 dS/m respectively. Soil pH (1:5) was slightly acidic in the upper three soil horizons, ranging from 5.2 to 6.5, and increased with depth to a pH (1:5) of 9.3 at the base of the profile. Soil pH_{CaCl_2} measurements were within 0.2 pH units of pH (1:5) values (Figure 6-13). Total organic carbon results were generally higher in the upper portion of the profile and ranged from 6.9% in the surface Oe1 horizon to 1.3% in the 2Bw horizon. Total sulfur measured 0.08% in the surface Oe1 horizon and increased slightly with depth, to a maximum of 0.56% in horizon Oe3. Carbonate content measured zero in the upper four horizons and 36.1% at the base of the soil profile (40 to 65 cm depth) in the 3Bg/W1 horizon. The soil morphology for profile BG 22 is detailed in Table 6-12.

Table 6-12 Summary of soil morphology for profile BG 22: Moist (winter), moderately well drained peaty soil. Soil colour was determined on moist samples and consistence was determined on dry samples. Photos are of dry samples.

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Oe1 (BG 22-323)	0-5	Dark greyish brown (10YR4/2) organic rich loam (25% mineral, 75% organic matter) with abundant (20%) fine live and dead roots. No mottles; friable structure; weak consistency without coarse fragments; gradual wavy boundary	
Oe2 (BG 22-324)	5-15	Dark greyish brown (10YR4/2) organic rich clay-loam (45% mineral, 55% organic matter) with abundant (20%) fine and coarse live and dead roots. Minor strong brown (7.5Y4/6) mottles (5% volume) along root channels and ped surfaces; subrounded blocky structure; weak consistency without coarse fragments; gradual wavy boundary	
Oe3 (BG 22-325)	15-25	Dark greyish brown (10YR4/2) organic rich clay-loam (50% mineral, 50% organic matter) with abundant (20%) fine dead roots. Minor strong brown (7.5Y4/6) mottles (5% volume) along root channels and ped surfaces; subangular blocky structure; weak consistency without coarse fragments; sharp wavy boundary	
2Bw (BG 22-326)	25-40	Greyish brown (10YR5/2) medium loamy sand with minor yellowish red (5YR5/8) mottles (5% volume) impregnating matrix of peds and on fine root channels. Subrounded blocky structure; weak consistency without coarse fragments; non calcareous; very few roots; gradual diffuse boundary	
3Bg/W1 (BG 22-327)	40-65	Olive grey (5Y4/2) medium sandy clay with minor yellowish red (5YR5/8) mottles (2-5% volume) impregnating matrix of peds and on shell surfaces. Subangular blocky structure; weak consistency with medium to coarse shell fragments; calcareous; no roots.	

Soil profile BG 22 classifies as: Aeric Haloquepts (Soil Survey Staff 2010); Haplic Hypersalic Hydrosol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil pH measurements were made on soil samples from all 5 soil layers using a 1:1 soil-water mixture (pH_W), after treatment with peroxide (pH_{OX}) and after ageing ($pH_{Incubation}$) the soil in a moist environment for up to19 weeks. Soil-water pH (pH_W) data show that soil layers range from acidic (pH_W 4.7) to circum-neutral (pH_W 7.5) at the base the profile. Peroxide oxidation tests (pH_{OX}) showed no significant drop in pH (from a pH_W of > 4 to a resultant pH_{OX} of 2.5 or less) in any of the samples, indicating they are unlikely to contain hypersulfidic material (Figure 6-13). After incubating soil samples, none experienced a significant drop in pH to less than pH 4, supporting the pH_{OX} data. Four of the five samples showed a slight rise in pH of between 0.5 and 1 pH unit after incubation.

Existing acidity (Titratable actual acidity (TAA) and Retained acidity)

pH_{KCl} results for four of the five samples analysed were > 6.5, indicating they did not contain Existing Acidity. The B1 horizon had a pH_{KCl} of 6.18 but no TAA was measured. pH_{KCl} ranged from 6.2 to 9.3. Retained acidity was considered zero as all pH_{KCl} results were well above 4.5 and no jarosite was observed in the samples.

Acid Volatile Sulfur (AVS)

All five samples were analysed for AVS due to dark grey matrix colours being present. An AVS content of 0.01% was detected only in the surface Oe1 horizon (0-5 cm) only (Figure 6-13).

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was determined for all five layers within the profile. S_{CR} values were very low (0.01%) in the upper three O horizons. S_{CR} measured 0.05% in the 2Bw horizon (25 to 40 cm), and 0.22% in the 3Bg/W1 horizon (40-65 cm), indicating they contain notable Potential Sulfidic Acidity.

Acid Neutralising Capacity (ANC)

Effective ANC was only detected in the 3Bg/W1 horizon (12.4% $CaCO_3$).

Net Acidity

Net acidity values were low but positive for the upper four soil horizons, ranging from 4 to 33 mole H^+/tonne. Net acidity of the 3Bg/W1 horizon was very negative (measuring -1507 mole H^+/tonne) (Figure 6-13).

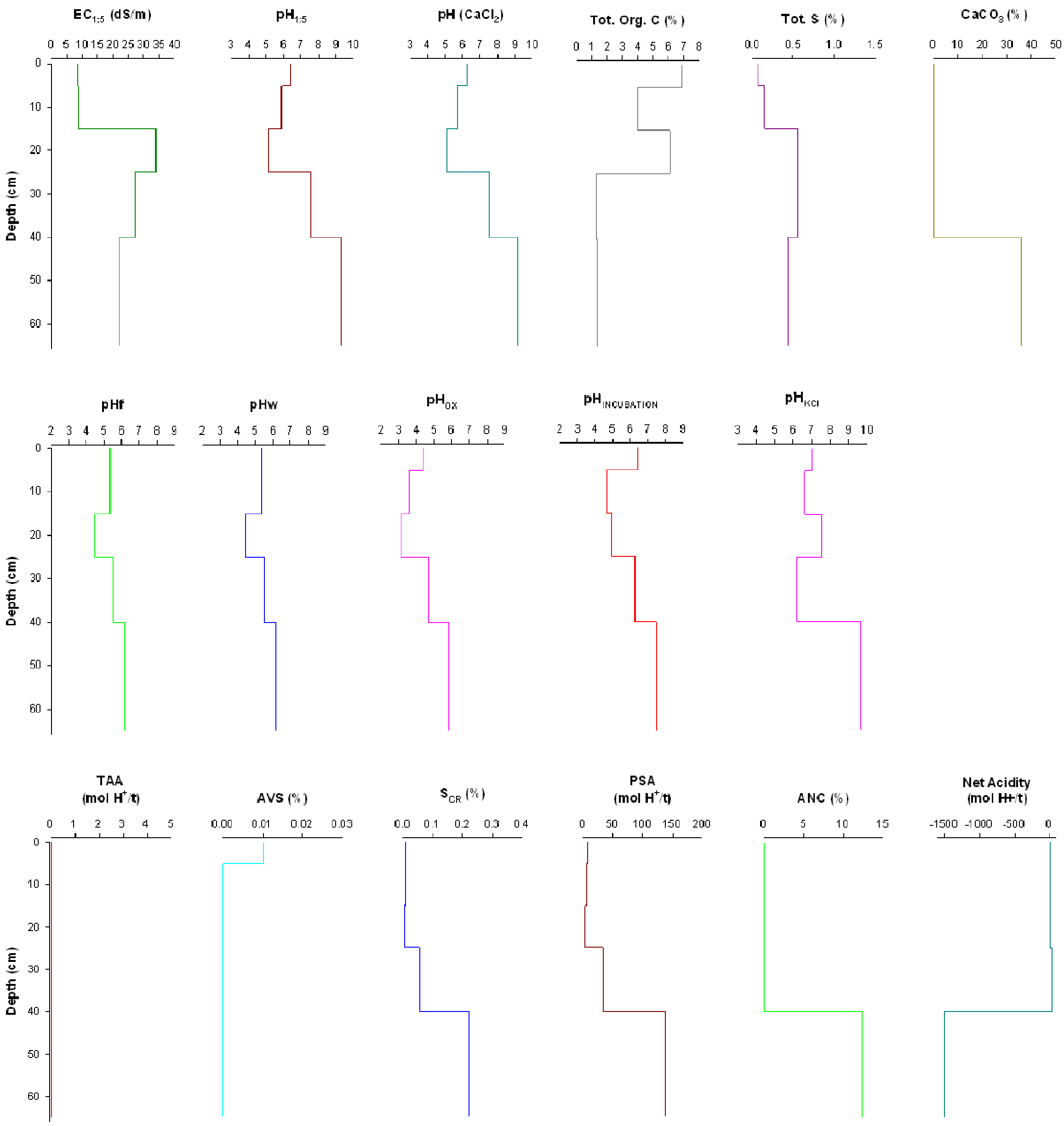


Figure 6-13 Down profile soil chemistry and acid sulfate soil characteristics of profile BG 22.

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-2), soil profile BG 22 classifies as an acid sulfate soil, containing hyposulfidic material, with minor monosulfidic material. Soil profile BG 22 does not contain sulfuric material.

Summary – Gillman Focus area C

Toposequence C-C' traverses across the bund wall from intertidal samphire to former tidal creek sediments. The soil profiles from map units 3 and 4 represent the 'drained' equivalent of map units 10 and 11 (Figure 6-11).

Oxidation of sulfides has lowered soil pH (although not forming sulfuric material) and removed carbonate from the drained soil profiles. The loss of tidal flushing has caused reduced inorganic sulfur contents to build up at the lowest positions in the landscape. These areas are represented by map units 1 and 2 and contain subaqueous and seasonally inundated soil profiles (e.g. BG 30 and BG 28). Reduced inorganic sulfur contents recorded in the disturbed area of Gillman Focus area C were highest in subaqueous soil profile BG 30 (with an AVS of 1.2% and a S_{CR} of 1.7%) (Appendix B). The maximum reduced inorganic sulfur contents found in tidally flushed subaqueous soil, within Barker Inlet, was from profile BG 24 (AVS of 0.32% and a S_{CR} of 0.72%; Appendix B). Reducing environments within the bunded (formerly tidal) area at Gillman generally contained higher levels of S_{CR} and AVS than soils within tidally influenced areas.

Soil profiles BG 21 and BG 20, within the intertidal zone and both classify as Hemic, Sulfidic, Intertidal Hydrosols (Isbell 2002), and Sulfic Hydrowassents (Soil Survey Staff 2010), containing hypersulfidic and hyposulfidic materials and minor monosulfidic materials. Soil profile BG 24 was located in a tidal creek channel and classified as a Hemic, Epicalcareous, Intertidal Hydrosol (Isbell 2002) and a Typic Hydrowassents (Soil Survey Staff 2010), containing hyposulfidic materials and monosulfidic materials (Table 6-13). These 3 soil profiles had similar chemical characteristics to intertidal soil profiles at St Kilda (occurring within the comparable map units).

On the southern (non-tidal) side of the bund wall soil profile BG 30 occurs at the lowest position in the landscape and classifies as a Sodosolic Salic Hydrosol (Isbell 2002) and a Typic Hydrowassents (Soil Survey Staff 2010), containing; hyposulfidic and monosulfidic materials. Profiles BG 28 and BG 31 occurred in map unit 2. Profile BG 28 classified as an Epicalcareous Hypersalic Hydrosol (Isbell 2002) and Typic Haloquepts (Soil Survey Staff 2010), and contained hyposulfidic and monosulfidic materials. Soil profiles BG 31 classified as a Haplic Hypersalic Hydrosol (Isbell 2002) and a Aeric Haloquepts (Soil Survey Staff 2010), containing hyposulfidic materials (Table 6-13).

Soil profiles BG 22 and BG 32 were located within map units 3 and 4 and classified as Haplic Hypersalic Hydrosols (Isbell 2002) and Aeric Haloquepts (Soil Survey Staff 2010), containing hyposulfidic materials (Table 6-13).

Table 6-13 Gillman Focus area C soil profiles 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 - Gillman					
BG 21	**11.** Low growing salt marsh plants	Hemic, Sulfidic, Intertidal Hydrosol	Sulfic Hydrowassents	Hypersulfidic, Hyposulfidic, monosulfidic (minor)	35 cm @ 221mole H^+/t from 5 cm depth
BG 20	**10.** Mangrove woodlands	Hemic, Sulfidic, Intertidal Hydrosol	Sulfic Hydrowassents	Hypersulfidic, Hyposulfidic, monosulfidic (minor)	35 cm @ 100 mole H^+/t from 5 cm depth
BG 24	**9** Water	Hemic, Epicalcareous, Intertidal Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic	20 cm @ -1175 mole H^+/t from 0 cm depth including an AVS of 0.32%
Former intertidal zone -Gillman					
BG 28	**2.** Benthic mat and bare salt scalded mud flats	Epicalcareous Hypersalic Hydrosol	Typic Haloquepts	Hyposulfidic, monosulfidic	5 cm @ -72 mole H^+/t from 20 cm depth, including an AVS content of 0.25%
BG 22	**4.** Dense low heath - samphire shrublands	Haplic Hypersalic Hydrosol	Aeric Haloquepts	Hyposulfidic	40 cm @ 12 mole H^+/t from 0 cm depth
BG 32	**3.** Bare salt scalded mud flats	Haplic Hypersalic Hydrosol	Aeric Haloquepts	Hyposulfidic	60 cm @ 25 mole H^+/t from 0 cm depth
BG 31	**2.** Benthic mat and bare salt scalded mud flats	Haplic Hypersalic Hydrosol	Aeric Haloquepts	Hyposulfidic	10 cm @ -92 mole H^+/t from 15 cm depth
BG 30	**1.** Water	Sodosolic Salic Hydrosol	Typic Hydrowassents	Hyposulfidic, monosulfidic	30 cm @ -2367 mole H^+/t from 0 cm depth, including an AVS content of 1.1%

Gillman Focus area D

Focus area D is situated on the eastern side of The Grand Trunkway (roadway) and on the southern side of the bund wall that runs parallel to North Arm of Barker Inlet (Figure 6-1). This section of the bund wall was constructed in 1965 and drained intertidal to supratidal soils covered with mangrove and samphire vegetation (Belperio and Rice 1989). Focus area D encompasses a toposequence that traverses from a high earthen mound (profile GGT 2) to low lying (0.5 m AHD) grasses and samphire vegetation covering organic rich loam (profile GGT 5) of the St Kilda Formation (Figure 6-14). Profile GGT 2 had an elevation of 4.4 m AHD and was covered by salt tolerant grasses (map unit 8). The natural soil level at profile GGT 5 was covered by dense low heaths and grasses (map unit 4) (Table 6-14). The earth mound was built in 1993 as part of the Multi-Function Polis (MFP) Development Feasibility Study to assess the geotechnical response of the St Kilda Formation to loading, mounding and pond stability (Kinhill Engineers Pty Ltd *et al.* 1996). The mound was constructed from layering imported fill material consisting of locally excavated St Kilda Formation soils and Port River dredgings (Thomas and Fitzpatrick 2006c). The mound has three levels; 1 m, 2.4 m and 4.4 m above natural ground surface (Figure 6-15). Full descriptions are provided for soil profile GGT 2 in this section as soil characteristics for map unit 8 have not been described previously. Soil profile GGT 5 is summarised in Table 6-16. Detailed morphological descriptions of profile GGT 5, including photographs of soil samples and plotted soil chemical data is provided in Appendix B.

Table 6-14 Soil profiles selected to be representative of map units occurring within focus area D, and along toposequence transect D-D’ in Figure 6-14 and Figure 6-15.

Soil profile numbers	Elevation	Map unit no.	Landform	Water State, ponding and drainage
Disturbed intertidal to supratidal areas (Gillman study site)				
GGT 2	4.4 m AHD	**8.** Artificially filled areas and embankments	Embankments and raised (filled) former intertidal to supratidal zone	Dry to moist (winter), moderately to poorly drained
GGT 5	0.5 m AHD	**4.** Dense low heath - samphire shrublands	Open flat plain – lower former intertidal floodplain	Moist (winter), moderately well drained

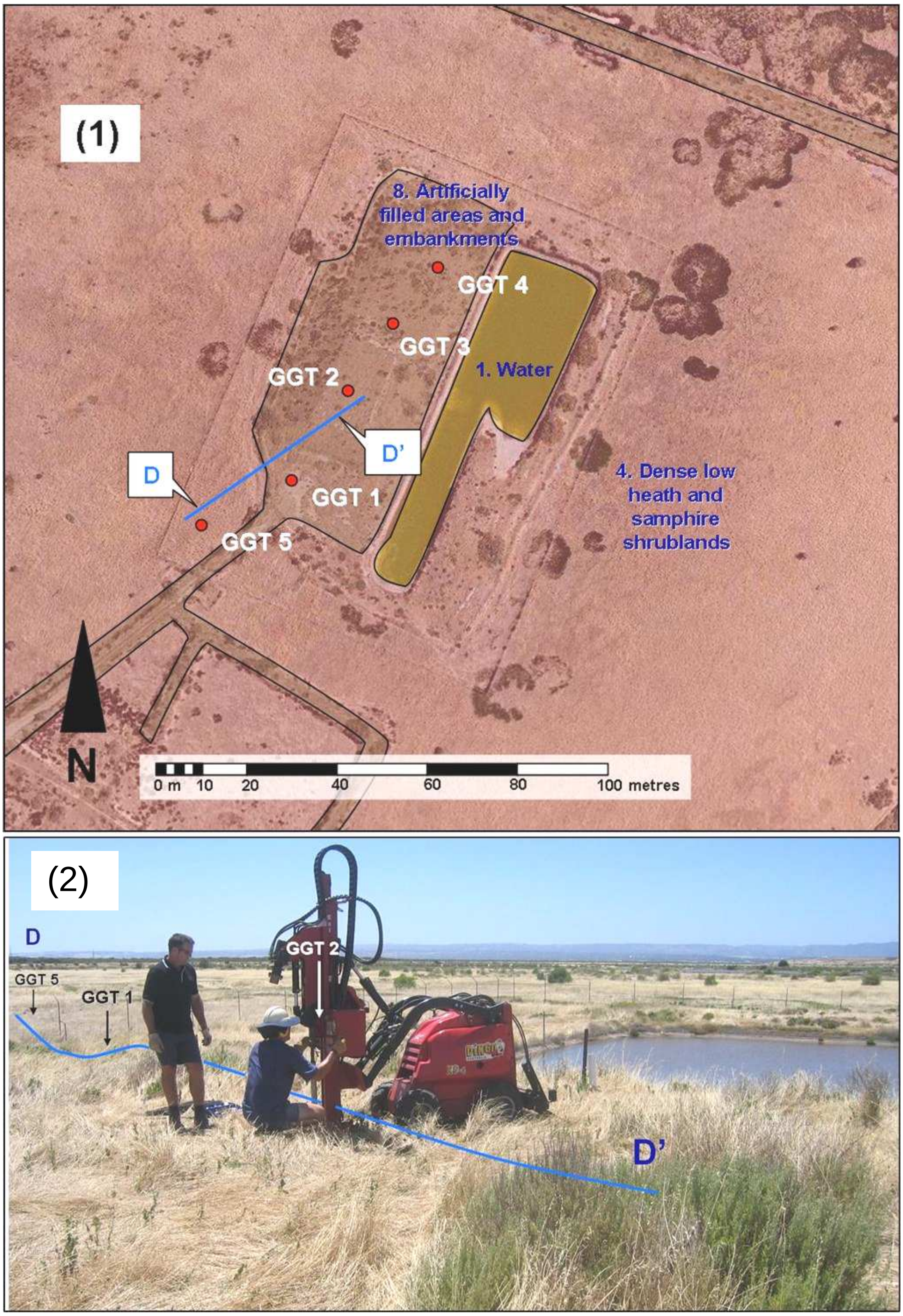


Figure 6-14 Transect D-D' indicating extent of map units and position of soil profiles. Soil profiles GGT 1, 2, 3 and 4 are located within map unit 8 and on the MFP test mound, having elevations of 1.5, 4.4, 2.4 and 2.3 m AHD respectively. Soil profile GGT 5 is located within map unit 4, on natural, formerly intertidal mangrove peat (0.5 m AHD).

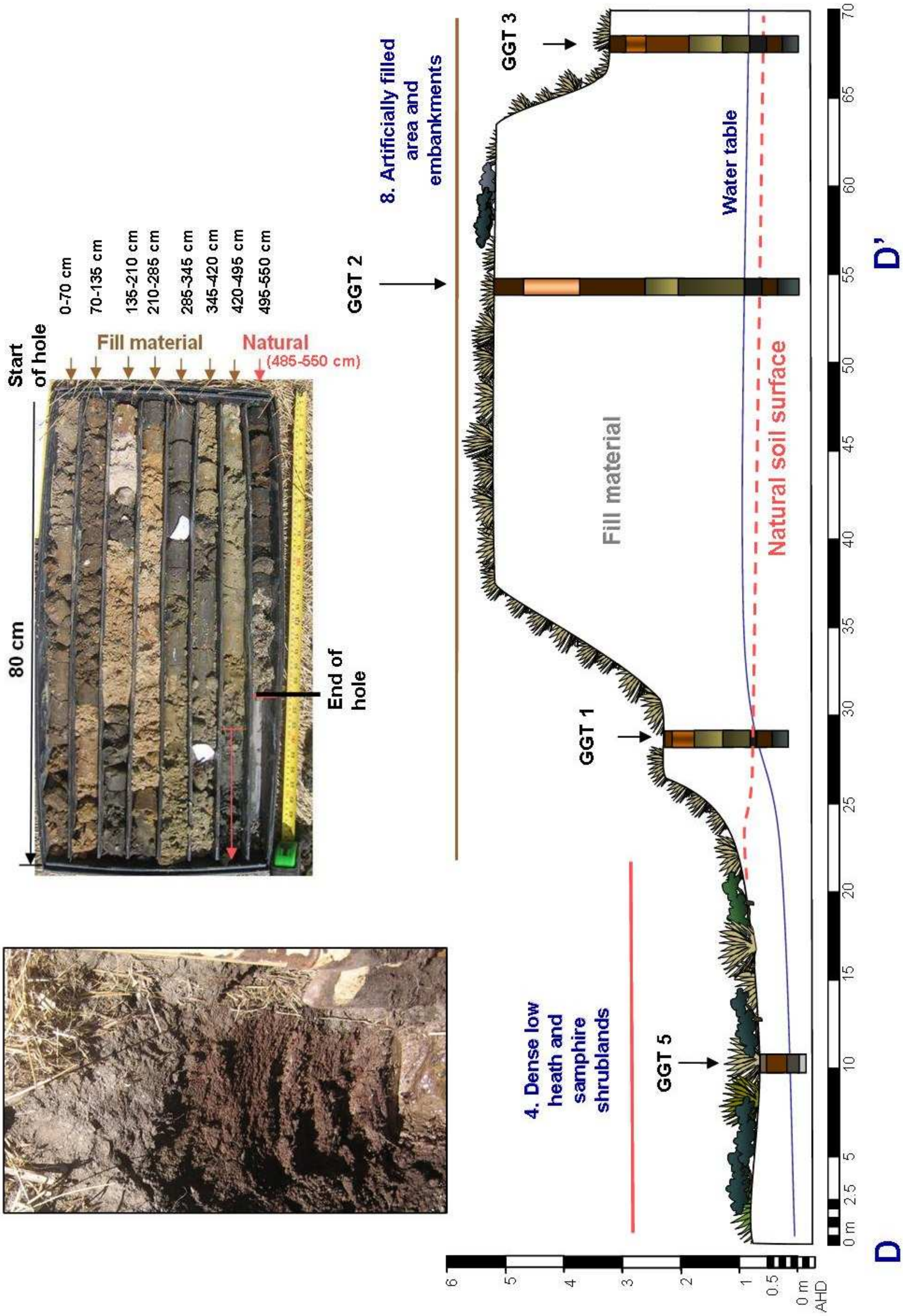


Figure 6-15 Descriptive soil-regolith toposequence model (cross section D-D' shown in Table 6-14) indicating map units, position and colour photographs of representative soil profiles or cores and average water table depth.

Map unit 8 - ***Dry to Moist (winter): moderately well to poorly drained, embankment and artificially raised (filled) former intertidal to supratidal floodplain. Profile GGT 2***

Soil profile GGT 2 occurs within map unit 8 (Artificially filled areas and embankments). Soil morphology for profile GGT 2 is provided in Table 6-15 together with a corresponding close-up photograph of soil fragments for each horizon or layer. Profile GGT 2 consists of over 4 m of fill material placed on former intertidal mangrove soils. The fill material consists of interlayered clays, sandy loams, shell grit and organic rich loams that were sourced from soil adjacent to the mound (during pond construction) and also from dredge spoil. The dredge spoil was originally Port River sediments that were hydraulically placed (forming playas) onto land west of the Grand Trunkway in the 1950s, then quarried for use in the MFP mound in 1993 (Thomas and Fitzpatrick 2006c). Fill material extends from the surface to 495 cm depth (Figure 6-15).

The surface Ap horizon (0 to 5 cm) was dry, moderately well drained, pale brown sandy clay loam. It had a firm, subangular blocky structure and abundant live roots from a thick cover of salt tolerant grasses. The upper 495 cm of the profile was dominated by yellow to pale brown loam to sandy clay loam, with very few mottles and some interbedded shell grit and calcrete fragments. Dark grey mottles were evident in the lowest layer of fill material (490 to 495 cm), indicating reducing conditions and the likely occurrence of monosulfidic material (Table 6-15). At the time of sampling, the groundwater table was at 472 cm from the surface (23 cm above the buried, natural soil layers). Dark grey mottles (10% by volume) were more evident in the top layer of the buried natural soil material (495 to 500 cm), consisting of organic rich loam (horizon 3Abg/W1). The underlying 4Abg/W1 horizon (500-515 cm) had fewer dark grey mottles (5% by volume) within an organic sandy loam matrix. A gleyed, greyish brown sand layer (horizon 5Bgg/W1) occurred from 515 to 530 cm. A calcareous 6Bg/W1 horizon occurred at the base of the profile and contained very coarse shell fragments with yellowish red staining on some shell surfaces (Table 6-15).

Within the fill material ECs were relatively low, ranging from 2.5 dS/m at the surface Ap horizon and within the lowest layer of fill material (horizon 2Ap7), to 4.8 dS/m in horizon 2Ap3 (175 to 205 cm) in the centre of the mound. The natural, organic rich soil layers had similarly low ECs. The 6Bb/W1 horizon however, had high EC (14.2 dS/m) due to saline groundwater (Figure 6-16).

Soil pH (1:5) was near neutral to slightly basic in fill material and in the calcareous layer at the base of the profile (Figure 6-16). The lowest pH (1:5) of 6.39 was detected in the organic rich sandy loam (4Bbg/W1 horizon) within the natural soil material. Soil pH_{CaCl_2} measurements were between 0.1 and 0.5 of a pH unit lower than the pH (1:5) results (Figure 6-16).

Total organic carbon contents were generally lower in the fill material (ranging from 2.8 to 4.4%) than in the buried natural soil layers (ranged from 2.0% to 8.9%). Total sulfur contents were relatively low (<1%) for fill materials and compared to buried natural soil layers. Total sulfur contents of fill material ranged from <0.01% in the surface Ap horizon to 0.5% in 2Ap3 horizon. Total sulfur contents of natural soil materials ranged from 0.06% at the 3Abg/W1 horizon to 1.6% in the underlying 4Bbg/W1 horizon. Carbonate content of fill material was high (mean value of 20.7% $CaCO_3$) and was relatively consistent down the profile (Figure 6-16). The carbonate content in the upper three horizons of the natural soil layers averaged 1.1% $CaCO_3$. The carbonate content of the 6Bg/W1 horizon at the base of the profile measured 34% $CaCO_3$ (Figure 6-16).

Table 6-15 Summary of soil morphology for profile GGT 2: Dry, moderately well drained, artificially filled former intertidal floodplain. (Soil colour determined moist and consistence dry).

Horizon (ID)	Depth (cm)	Soil morphology	Sample (5 x 2.5 cm)
Ap GGT 2-1 371	0-5	Pale brown (10YR6/3) sandy clay loam without mottles; moderately coarse subangular blocky structure; firm consistency with coarse shell fragments; abundant fine roots; gradual boundary	
2Ap1 GGT 2-2 372	5-130	Very pale brown (10YR7/3) sandy clay loam without mottles; moderately coarse subangular blocky structure; firm consistency with some coarse shell fragments; many fine roots; gradual boundary	
2Ap2 GGT 2-3 373	140-160	Yellow (10YR7/6) loam without mottles; moderately coarse subangular blocky structure; weak consistency without coarse fragments; few medium shall fragments; very few roots; gradual boundary	

2Ap3 GGT 2-4 374	175-205	Yellow (10YR7/6) loam with some reddish yellow (7.5YR6/8) mottles (5% volume); medium subangular blocky structure; weak consistency without coarse fragments; few medium shall fragments; no roots; clear boundary	
2Ap4 GGT 2-5 375	205-235	Dark brown (10YR3/3) organic sandy clay without mottles; rounded structure; very weak consistency with few coarse shell fragments; no roots; clear boundary	
2Ap5 GGT 2-6 376	295-410	Pale brown (10YR6/3) sandy clay loam without mottles; medium subangular blocky structure; weak consistency with some coarse shell fragments; no roots; gradual boundary	
2Ap6	410-490	Very pale brown (10YR8/4) sandy clay loam without mottles; moderately coarse subangular blocky structure; weak consistency with some coarse calcrete fragments; few medium shall fragments; no roots; diffuse boundary	
2Ap7/W1 GGT 2-8 378	490-495	Very pale brown (10YR8/4) sandy clay loam with few very dark grey (10YR3/1) mottles (5% volume); moderately coarse subangular blocky structure; weak consistency with some coarse calcrete fragments; few medium shall fragments; no roots; diffuse boundary	
3Abg/W1 GGT 2-9 379	495-500	**Top of Natural St Kilda Formation.** Dark brown (10YR3/3) organic loam with few very dark grey (10YR3/1) mottles (10% volume); subrounded blocky structure; very weak consistency with no coarse fragments; non-calcareous; no roots; H_2S odour; clear boundary.	
4Bbg/W1 GGT 2-10 380	500-515	Brown (10YR4/3) organic sandy loam with few very dark grey (10YR3/1) mottles (5% volume); subrounded single grain structure; very weak consistency with no coarse fragments; non-calcareous; no roots; clear boundary	
5Bbg/W1 GGT 2-11 381	515-530	Greyish brown (10YR5/2) sand with no mottles; single grain structure; very weak consistency some medium to coarse organic fragments; few medium shell fragments; no roots; clear boundary	
6Bb/W1 GGT 2-12 382	530-550	White (10YR8/1) very coarse shell grit with few reddish yellow (7.5YR7/8) mottles (5% volume) as staining on shell surfaces; single grain structure; very weak; no roots	

Soil-sediment profile GGT 2 classifies as: Haplic Xerarents (Soil Survey Staff 2010) and a Sulfidic, Dredgic Anthroposol (Isbell 2002).

Acid Sulfate Soil Characteristics

Soil pH testing (pH_W, pH_{OX} and $pH_{Incubation}$)

Soil pH measurements were made for all layer samples in a 1:1 soil-water mixture (pH_W), after treatment with peroxide (pH_{OX}) and after ageing ($pH_{Incubation}$) the soil in a moist environment for 19 weeks. S oil-water pH (pH_W) values were circum-neutral for all layers however the natural, buried soil layers generally had slightly lower pH_W values than the fill material (Figure 6-16). Soil layers between 0 and 495 cm depth (fill material) had a pH_W range from 7.5 for soil horizon 2Ap3 (175 to 205 cm) to 6.6 in horizon 2Ap7/W1 (490 to 495 cm). The pH_W of soil layers below 495 cm depth (natural material) ranged from 6.1 and 7.5.

A drop of about one pH unit was observed for most samples following treatment with peroxide (Figure 6-16). The lowest pH_{OX} of 3.1 was measured in a natural sandy layer (515 and 530 cm). After incubating samples for up to 19 weeks, the lowest $pH_{Incubation}$ obtained was 5.9 (horizon 4Abg/W1), indicating that no soil layers contain hypersulfidic material. The vast majority of samples showed a slight rise in pH of between 0.5 and 1 pH unit following incubation (Figure 6-16). The high net acidity values subsequently measured in horizons 3Abg/W1 and 4Abg/W1 (refer below) suggested the incubation results were inaccurate and were therefore repeated. For the repeated incubation experiment bulk soil samples were sieved (2mm), homogenise prior to incubating in chip tray compartments for 19 weeks. The $pH_{Incubation}$ of horizon 3Abg/W1 measured 4.1, and 4Abg/W1 measured 3.6, indicating that horizon 4Abg/W1 contained hypersulfidic material. The discrepancy was probably due the samples not being homogenised sufficiently for the original incubation experiment. This issue is exacerbated in coarse grained samples due to the small amount of subsample portioned to chip tray compartments.

Existing acidity (Titratable actual acidity (TAA) and Retained acidity)

Only one of the seven samples analysed had a pH_{KCl} of < 6.5, indicating it likely contains a minor amount of Existing Acidity, and no effective acid neutralising capacity. The TAA for this sample (natural, organic rich sandy loam layer from 500 to 515 cm depth) measured 2.5 mole H^+/tonne. Retained acidity was not measured as no jarosite was observed in the layer samples.

Acid Volatile Sulfur

Four samples containing minor dark grey to black mottles were analysed for AVS. Acid volatile sulfur contents ranged from 0.00% in the lowest layer of fill material to 0.08% in a natural organic sandy loam layer occurring from 500 to 515 cm depth (Figure 6-16).

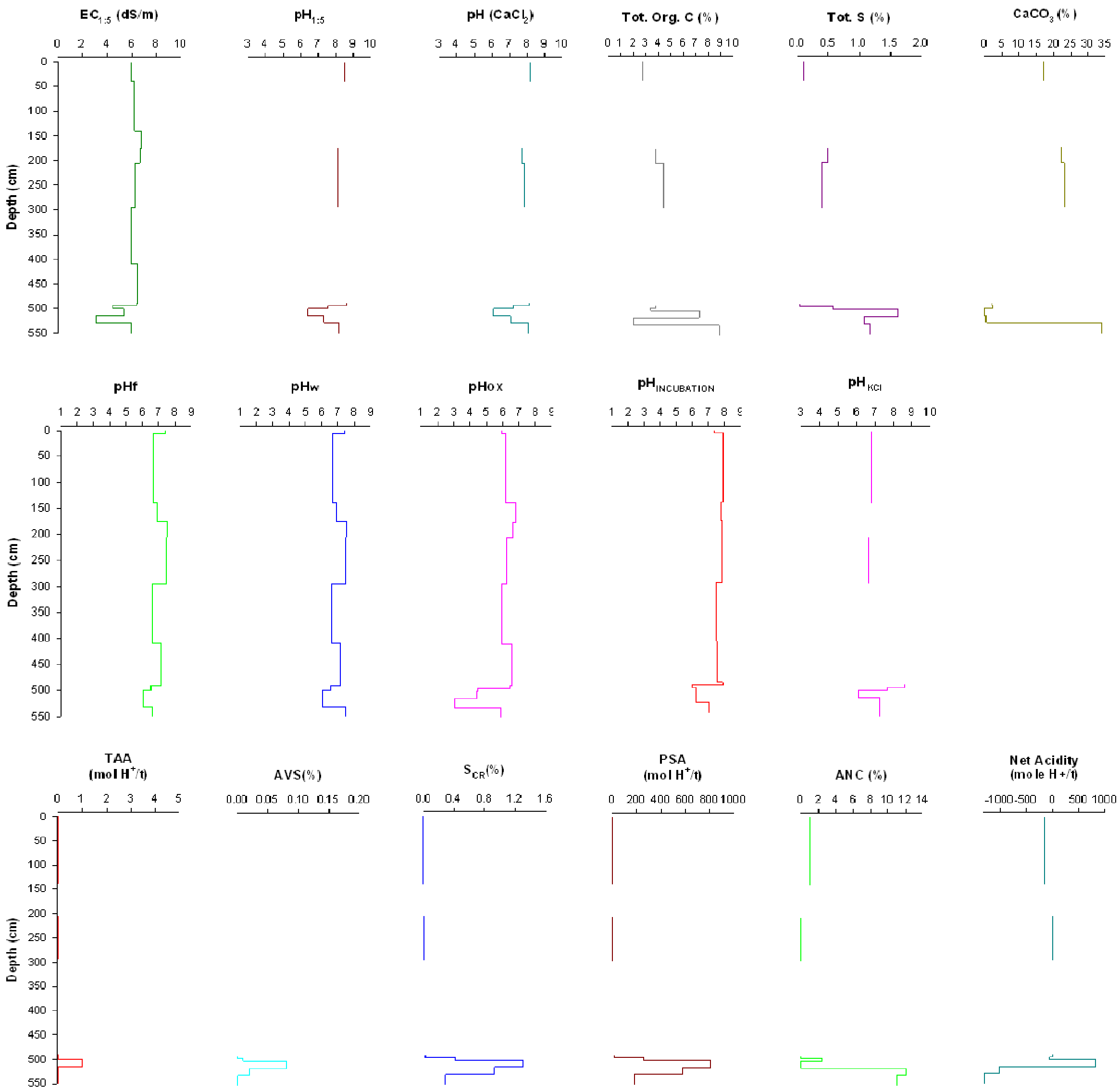


Figure 6-16 Down profile soil chemistry and acid sulfate soil characteristics of profile GGT 2.

Acid sulfate soil classification: According to the acid sulfate soil terminology adopted (refer to Table 4-1), soil profile GGT 2 classifies as a buried acid sulfate soil, containing hypersulfidic, hyposulfidic material and monosulfidic materials.

Chromium Reducible Sulfur (S_{CR})

Reduced inorganic sulfur was determined for seven samples within soil profile GGT 2. S_{CR} contents were very low in the fill material and ranged form 0.00%S_{CR} to 0.03%S_{CR}. High S_{CR} contents were measured in all natural soil materials and ranged from 0.29%S_{CR} at the base of the profile (horizon 6Bg/W1) to 1.30%S_{CR} within the organic rich sandy loam layer at 500 to 515 cm depth (Figure 6-16).

Acid Neutralising Capacity (ANC)

ANC was high (11.4% $CaCO_3$) within the calcareous layer near the base of the soil profile, and relatively low elsewhere (ranging between 0 and 3.4% $CaCO_3$).

Net Acidity

Net Acidity within fill material ranged from 4.4 mole H^+/tonne to -133 mole H^+/tonne, with an average of -86 mole H^+/tonne. Two natural organic rich soil layers (between 500 and 530 cm depth) had positive net acidities, measuring 835 mole H^+/tonne and 426 mole H^+/tonne. The other natural soil layers had negative net acidity values of -57 mole H^+/tonne in horizon Ap1 and -1338 mole H^+/tonne in the lowest soil horizon (6Bb/W1) (Figure 6-16).

Summary – Gillman Focus area D

Toposequence D-D’ transects from an elevated, artificial mound (map unit 8) to former intertidal mangrove and samphire sediments (map unit 4) (Figure 6-15). The soil profile through the mound (GGT 2) classifies as a Sulfidic, Dredgic Anthroposol (Isbell 2002) and a Haplic Xerarents (Soil Survey Staff 2010), containing, hypersulfidic, hyposulfidic materials and minor monosulfidic materials. The mound was placed on formerly intertidal mangrove and samphire sediments that was similar to soil profile GGT 5 which classifies as a Sulfuric, Salic Hydrosol (Isbell 2002), Typic Sulfaquepts (Soil Survey Staff 2010), containing sulfuric material and hyposulfidic materials (Table 6-16). Refer to Appendix B for a detailed description of profile GGT 5.

Profile GGT 2 contains over 4 m of fill material sourced from dredgings and locally excavated soil. The fill material probably contained some sulfidic material prior to the mound being formed. Oxidization of sulfides is evidenced by some strong brown iron oxide mottles that were most abundant as coatings on shell fragments. Some sulfide has is preserved in organic rich layers of fill material above the water table.

The mound has compressed the underlying St Kilda Formation soils, pushing the original soil surface below the watertable. The original soils probably contained both sulfuric and sulfidic materials prior to burial, (resembling profile GGT 5). Any existing acidity originally present in the soil profile was likely neutralised following burial by at least three processes: **i)** exclusion of oxygen which allowed reducing conditions to re-establish and iron sulfides to form, **ii)** acidic soil layers being pushed into contact with bicarbonate bearing groundwater, and **iii**) rain water that passes through >4 metres of calcareous materials contained bicarbonate.

Soil profile GGT 5 has similar morphology and characteristics to other soil profiles located within map unit 4, such as profile BG 22, BG 32 (described for Gillman Focus area C) and BG 29 (refer to Appendix B).

Table 6-16 Gillman Focus area D 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
GGT 2	**8.** Artificially filled areas and embankments	Sulfidic, Dredgic Anthroposol	Haplic Xerarents	Hypersulfidic, Hyposulfidic, monosulfidic	20 cm @ 631 mole H^+/t from 500 cm depth
GGT 5	**4.** Dense low heath - samphire shrublands	Sulfuric, Salic Hydrosol	Typic Sulfaquepts	Sulfuric, hyposulfidic	70 cm @ 272 mole H^+/t from 0 cm depth

6.2. Summary – Gillman study site

Eleven map units identified at the Gillman study site are inherently linked to the hydrological and pedological characteristics of the area, which are predominantly controlled by geomorphology, micro-elevation, hydrology and vegetation (source of organic matter). Therefore the map units, discernable by aerial photography were related to the geomorphology and topography to improve their correlation to acid sulfate soil characteristics, and soil processes. Correlations between map units and soil types at the Gillman study site are presented in Table 6-17.

Soil-water pH (pH_W) ranged from 1.5 (in profile BG 15) to 8.14 (in profile BG 11). Soil pH_W data indicated that five soil profiles contained sulfuric materials that predominantly occurred in profiles located in map units 5 and 6. Soil incubation experiments indicated that net acidity of hypersulfidic material was highest sandy soil layers occurring close to or below the redox front.

Soil profiles within map unit 5 contained both (i) very high existing acidity and (ii) very high potential sulfidic acidity values. Sulfuric material identified in organic rich soil profiles from map units 4 and 3 had considerably lower net acidity contents (e.g. profiles BG 22, BG 32 and GGT 5). All 16 soil profiles contained potential sulfidic acidity in the form of reduced inorganic sulfur. The highest S_{CR} content (7.05%) was measured in soil profile BG 4, located within map unit 2. The highest AVS content of 3.48% was also measured in profile BG 4. Modest AVS contents (> 0.2%) were detected in most soil profiles from map units 1, 2, and 9, due to the presence of saturated or subaqueous soils. Minor concentrations of AVS were also measured within a buried organic-rich layer in profiles GGT 2, and BG 2 (Appendix C) which are located in map unit 8.

The correlations that have been established between landscape features and soil characteristics at Gillman (Table 6-17) and St Kilda (Table 5-12) are used in Chapter 7 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 6-17 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 Haloquepts Aeric Haloquepts	Hypersulfidic, hyposulfidic, monosulfidic
3. Bare salt scalded mud flats	**BG 17, 32**	Sulfuric, Salic Hydrosol Haplic, Hypersalic Hydrosol	Salidic Sulfaquepts Aeric Haloquepts	Sulfuric, hypersulfidic, hyposulfidic, monosulfidic
4. Dense low heath -samphire shrublands	**BG 22, GGT 5**	Haplic, Hypersalic Hydrosol Sulfuric, Salic Hydrosol	Aeric Haloquepts 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

At Gillman a chenier deposit (shell grit layer) was intersected at the base of profiles BG 24, BG 22, BG 28, BG 32, GGT 5 and GGT 2, and had an average acid neutralising capacity of -1711 mole H^+/tonne. The high acid neutralising capacity and extensive spatial distribution of the layer (which occurred commonly in map units 2, 3 and 4) initiated the introduction of a transparent map unit for the soil map presented in Chapter 7 to indicate where the chenier deposit occurs within 25 cm of the soil surface. Minor occurrences of thin, discontinuous, shelly layers were observed in profiles from map units 5, 6 and 7, but these generally occurred as re-worked (by wave action) material at or near the surface.