

**Coastal acid sulfate soil
processes in Barker Inlet, South
Australia**

Doctor of Philosophy

The University of Adelaide

School of Earth and Environmental Sciences

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Brett Peter Thomas

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Selected publications related to this thesis

Refereed Scientific Journal publications

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Summary

Acid sulfate soils occur in dynamic and geomorphologically complex inland and coastal landscapes that are inherently susceptible to natural and human induced changes. These changes can lead to environmental degradation and loss of infrastructure through acidification of soil and water and metal mobilisation. This study has identified and described the interrelationships between acid sulfate soil materials and their geomorphic environment, composition (pedology, mineralogy), redox status and geochemistry, and potential environmental hazards, within a complex estuarine landscape in the Barker Inlet region, north of Adelaide, South Australia.

For this purpose two study sites were chosen within Barker Inlet, namely Gillman and St Kilda. The Gillman site was chosen because it was known to have problem acid sulfate soils with sulfuric material and was ideally suited for comparative research because it contained “paired sites” with intertidal soils abutting an area that had been reclaimed for industrial development. The reclaimed land at Gillman was non-tidal due to the construction of bund walls 75 years ago. An intertidal site at St Kilda was selected as a control site and to assess the influence of tidal variations on soil properties.

The aims of this study were to:

- (i) conduct detailed field and laboratory examinations to characterise the range of soil types occurring across the tidal and disturbed (formerly tidal) landscapes,
- (ii) construct detailed soil maps to relate the data spatially to hazards associated with soil types and landscape features within the study sites, and
- (iii) construct descriptive and predictive conceptual soil-regolith models to validate and increase understanding of environmental degradation processes occurring within these complex acid sulfate soil landscapes.

A review of the natural history and previous research work was conducted in conjunction with a preliminary soil survey of the Gillman and St Kilda study sites and these indicated that areas most vulnerable to contamination and acidification were geomorphically controlled. Detailed soil surveys were then conducted to target the typical landscape features at the study sites (i.e. focus areas). Detailed acid sulfate soil characterisation and mapping of soil types within the focus areas allowed surface cover types from aerial photography to be used as a surrogate for accurately mapping acid sulfate soil types. Soil maps were produced, in this manner, covering the two study sites. For management purposes, this enabled map units to be assigned descriptive properties that included ‘hazard classes’ and ‘acid sulfate soil treatment categories’.

New, *in-situ* soil redox monitoring methods were developed to reliably measure Eh in 14 selected soil profiles over extended periods of time within contrasting tidal and non-tidal environments. Redox data loggers continuously recorded redox measurements at depth increments ranging from +10 cm (surface water) to 2 m below the soil surface. Results showed that significant changes in redox status occurred at sub-hourly timeframes in both tidal and non-tidal soils. Tidal environments were characterised by large, cyclic fluctuations in redox conditions, which were proportional to the timing and strength of tidal currents. When freely draining mangrove soils were exposed at low tide, redox conditions generally became more oxidising. However, soil that remained submerged in tidal creeks during low tide become more reducing due to less movement and mixing of surface water. Storm events and seasonal variations influenced soil and water redox conditions for non-tidal environments (i.e. reclaimed land at the Gillman site). Redox conditions within some sulfuric materials alternated seasonally between oxidising and strongly reducing, causing oxidation and subsequent re-formation of pyrite. Storm-related disturbance of subaqueous soils at Gillman initially caused redox potential (Eh) in the water column to decrease, due to the dispersion of monosulfidic material.

Developing the ability to link soil and water contaminant issues to soil map units was particularly important for the non-tidal area at Gillman because elevated concentrations of potentially toxic elements (As, Ba, Co, Cu, Pb, V and Zn) were identified and these were related to historic land use (industrial) and landforms. Results indicated that trace metals were concentrated in surface soil layers of the more elevated areas containing sulfuric material as well as in low lying areas containing monosulfidic material. Trace metals were more concentrated at depth in soil profiles at Gillman that were subjected to seasonal flooding. This is due to redox conditions in the upper portion of the soil profile alternating seasonally from oxidising to reducing, and causing trace metals to accumulate at the summer redox front where iron sulfides remain stable as well as form during wet months. Acidic soil conditions promoted migration down the profile of trace elements, which were scavenged by salt efflorescences that formed on soil surfaces near the water table. Dissolution of salt efflorescences following rain events negatively impacted drainage water quality, mainly by release of Al, Fe and acidity.

Salt efflorescence mineralogy was a result of characteristic Mediterranean type climate, hydrogeology, saline seepages, and salt crusting formed in drains above sandy sulfuric, hypersulfidic and hyposulfidic materials. This study documented the first occurrence of sideronatrite [$\text{Na}_2\text{Fe}(\text{SO}_4)_2(\text{OH})\cdot 3\text{H}_2\text{O}$], tamarugite [$\text{NaAl}(\text{SO}_4)_2\cdot 6\text{H}_2\text{O}$] and alunogen in coastal acid sulfate soils in Australia. They formed together with starkeyite, pentahydrate, gypsum and some halite on the exposed face of soil pits and drains at Gillman. These Fe/Al oxyhydroxysulfate and oxyhydroxide minerals are indicators of very acidic soil conditions (i.e. indicate the presence

or former presence of oxidised pyrite), and as such their identification provides an important environmental indicator of acid sulfate soil processes. Descriptive and predictive soil regolith models were constructed to describe and explain the origin of these minerals at the Gillman study site. The models were tested by constructing experimental drains through sulfuric material at the Gillman site.

Micromorphological studies helped to identify features indicative of contemporary and relic processes within acid sulfate soils and verify soil characteristics within tidal and non-tidal environments. The results indicated that micro-environments of pyrite oxidation can control bulk soil pH, particularly in sandy soil profiles with little buffering capacity. The varied morphology and composition of pyrite crystals and framboids, and goethite pseudomorphs after pyrite, were used as palaeo-indicators of the soil physio-chemical conditions. The morphology and composition of pyrite oxidation products indicated oxidation rates and carbonate availability. Microanalysis of sulfidic materials and sulfide oxidation products (including salt efflorescences) assisted in identifying migration pathways of trace elements through the landscape. The preservation of pyrite crystals within oxidising environments was identified to occur by armouring with clay coatings and by pyrite framboids being overgrown by (or included within) gypsum and halite crystals. Armouring of pyrite in soils has implications for the characterisation of acid sulfate soil types using ageing experiments, as well as for hazard assessment and management, by underestimating the potential sulfidic acidity of some soil materials.

The development of descriptive and predictive conceptual soil-regolith models was based on the integration of all results to provide a holistic understanding of the coastal landscape and the impact of acid sulfate soils on the environment. The information and mapping techniques developed here were used to construct local and regional scale acid sulfate soil hazard maps. This information was used in the production of Coastal Protection Board policy documents and educational material underpinning risk-based acid sulfate soil management options for coastal developments in South Australia, and was specifically integrated into new master development plans for the Gillman area.

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Figures

Figure 1-1 Barker Inlet is located 20 km north of Adelaide, South Australia. Large tracts of intertidal and supratidal land surrounding Barker Inlet have been reclaimed since the early 1900s by the construction of 2-4 m high bund walls to preclude tidal inundation. The two sites that form the focus of study for this thesis were selected for their contrasting drainage histories. The St Kilda study site has largely remained un-altered and contains intertidal mangrove and samphire vegetation in a conservation area. Intertidal and supratidal areas at the Gillman study site have been progressively drained since the 1930s, for industrial purposes. Land reclamation in the Gillman area has caused the oxidation of sulfidic material and formation of sulfuric material which has acidified groundwater and severely degraded the landscape. Aerial photo was taken in March 2010.....5

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Figure 3-2 The Gillman study site is predominately vacant, consisting open grasslands, samphire shrublands and salt and sand flats. It is bordered by urban and industrial development to the south and abuts tidal mangrove woodland along North Arm. The Gillman area has been progressively reclaimed from the intertidal and supratidal environments of Barker Inlet since the 1930s by construction of a series of bund walls that prevent tidal inundation.27

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