Acid sulfate soil depositional environments of the Barron River delta, North Queensland

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Abstract
An acid sulfate soil map for the Cairns area was completed by Department of Environment and Resource Management (DERM) in 2009 (Manders *et al.* 2009). Investigation of field morphological properties and laboratory data from sites examined during the Cairns ASS mapping reveals that sites within geomorphologically similar areas can be extrapolated to spatially predict the upper limit of ASS deposition. This paper discusses the ASS depositional environments encountered on the Barron River delta within geomorphologically similar areas reflect these depositional environments.

Introduction
Coastal Acid Sulfate Soils (ASS) are soils or sediments containing iron sulfides, primarily in the form of pyrite (FeS_2). They commonly form in coastal environments where a supply of iron, sulfate, and organic matter are available to bacteria in an anaerobic environment. ASS have been forming for many thousands of years and can be encountered in at least 23,000 km^2 of the Queensland coast, both at the surface and buried beneath newer soils (National Working Party on Acid Sulfate Soils 2000). ASS are relatively benign in their natural (wet or buried) environment but can be hazardous when disturbed, having the potential to cause widespread environmental damage via the release of acid and metals from the soil.

The Barron River delta is located just north of Cairns on the northeast wet tropical coast of Queensland and experiences hot and humid summers and mild dry winters. Sugar cane is the main land use for the delta and was first planted in 1879, with substantial industry expansion occurring in the 1960s. Other land uses include urban areas (located on the beach ridges), residential canal developments (low-lying areas behind the beach ridges), and sand mining (upper riverine reaches). The delta's position in the landscape has provided an ideal environment for the aforementioned ASS formation factors to interact throughout the Holocene.

Acid sulfate soil depositional environments
Acid sulfate soils are deposited in large areas under coastal plains because the rapid rate of sea level rise during the Holocene exceeded the rates of coastal deposition and thus valleys and low lying coastal areas were drowned. Once sea level stabilises (termed still stand), new estuaries are formed and coastal deposition processes are able to commence filling the newly created subaqueous space (Dalrymple *et al.* 1992). Marine sands are deposited as tidal deltas behind the barrier by incoming tides. In the upper reaches (dominated by river energy), fluvial sediments are deposited as bay head or fluvial deltas. The area of neutral energy (central basin) between the two is generally filled with finer sediment such as clays and silts. With time and a sufficient sediment supply, estuaries eventually fill with sediment and mature (Roy 1984). Once the central basins (or lagoons) are filled, river processes begin to build alluvium out over the top of the marine sediments during flood events.

Coastline evolution and ASS deposition
The Barron River delta is a wave dominated delta stretching from Earl Hill in the north to Ellie point in the south and Kamerunga at the headwaters of the delta in the west (OzCoast 2009) (Figure 1). Wave energy, in combination with tidal currents, causes sediment to move along shore (northwards drift) and onshore into the mouth of the estuary where a barrier such as a spit or submerged sand bar forms. The entrances of wave-dominated deltas are relatively narrow due to constriction by the formation of the sandbar, and due to the relatively high river influence they are rarely closed off from the sea. However migration of river channels is commonplace during delta development because the gradient and the capacity of the river to flow gradually decreases towards its exit point. The Barron River is no exception and has several prior channels, including Moon River, Yorkeys Creek, Thomatis Creek, Ritchers Creek, Barr Creek and Redden Creek. Moon River and Barr Creek are currently only connected to the Barron River through overland flow (Figure 1). All of these prior channels dissect the large beach ridge barrier and are flanked by low-lying areas colonised by mangroves.

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The beach ridge barriers prevent much of the wave energy from entering the estuary (Dalrymple *et al.* 1992). The barriers occur from Mt Whitfield located south of the Barron River, northwards to Yorkeys Knob. The supply of sand via northward drift to the beaches north of Yorkeys Knob has been disrupted by the protruding headlands (which include Yorkeys Point, Earl Hill, and Taylor Point) limiting the supply and formation of large beach ridge barriers north of the Barron River delta. The progradation of the Barron River delta has occurred by the extension of beach ridge barrier deposits over prodelta deposits. The beach ridge barrier deposits consist of a series of sand ridges with the intervening depressions colonised by either melaleucas or mangroves.

Identification of ASS horizons is based upon field morphological properties, pH results and laboratory analyses of sulfur content that exceed the texture-based action criteria (sands 0.03% S, loams 0.06% S and clays 1.00% S; Ahern *et al.* 1998). The elevation (metres AHD) of the sites mapped (calculated from airborne laser profiling of Light Detection and Ranging (LiDAR) ground point extraction) minus the depth to the ASS layer (where the action criteria is exceeded) gives the relative upper limit (m) AHD of ASS and a comparison between sites.

Beach ridges are high energy environments, and as such are not conducive to ASS formation and generally have an average concentration of 0.2% S in loam to coarse sands above prodelta muds. The sites sampled (Table 1) within the beach barrier recorded an average ASS upper limit of -1.0m AHD.

Table 1. Beach Ridge Barrier Sites

	Sites (m) AHD					Average	Median	Standard Deviation
Elevation	4.80	2.25	1.94	4.25	3.69	3.4	3.69	1.25
Depth to ASS	5.05	3.45	3.45	5.00	4.80	4.4	4.8	0.83
Upper Limit of ASS	-0.25	-1.2	-1.5	-0.75	-1.1	-1.0	-1.1	0.48

The back barrier low-lying mangrove colonised swales situated directly behind the beach ridges have a high tidal exchange and are ASS at or near the surface. The sites sampled (Table 2) have an average upper limit of ASS at 0.9m AHD. ASS will not normally form above the 0.5m AHD (based upon mapping in South East Queensland) level due to the oxidation during the wetting and drying cycle between tides. The occurrence of ASS within mangrove areas (>1.0m AHD elevations) can be variable at the surface. The back barrier low-lying mangrove areas with low energy environments combined with the high tidal exchange promotes the formation ASS at higher than normal upper limits.

Table 2. Mangrove Swales

	Sites (m) AHD			Average	Median	Standard Deviation
Elevation	0.9	1.05	1.0	1.0	1.0	0.08
Depth to ASS	0.0	0.2	0.0	0.1	0.0	0.12
Upper Limit of ASS	0.9	0.85	1.0	0.9	0.9	0.08

Where no hydrological modification or vegetation clearing has occurred mangrove communities have colonised most of the supratidal and extratidal areas up to the 1.7m AHD. This has resulted in the presence of only small areas of saltmarsh communities with in the mapping area. A number of factors contributing to the poor development of saltmarsh areas include the presence of the steep coastal plain, the coarse sedimentary composition of the coastal deposits and the area's high rainfall. Some hydrological modification of the delta has occurred with a series of bund walls and floodgates constructed to keep tidal inundation and storm surges out of low-lying land while allowing for flood water to escape. The areas protected by bund walls have been cleared of mangroves in the elevation range 1.0 - 1.7m AHD. These areas are used to grow sugarcane but often they have undergone oxidation and have become acidic in the surface layers.

The central basin of the delta is dominated by fine clays, however sands tend to dominate where the river channels have migrated across the delta. Approximately 50 sites were sampled in the central basin with the elevation of the sample sites varying from 1.7m to 4.4m AHD. The average elevation of the sites was 2.63m AHD, the average depth to ASS was 2.79m AHD, and the average upper limit of ASS was -0.16m AHD.

The upper reaches of the delta are dominated by river energy with riverine (non-marine) sands deposited over ASS clays and sands. The land surface varies from 4m to 7m AHD in height, with major floods removing and redepositing surface material. The site with the upper limit of ASS at -2.1m (Table 3) is

located on the southern bank of the Barron river. The site consists of alluvial clay loam to 1.4m over riverine coarse sands to 7.0m, ASS sands occur from 7.0m to the depth of sampling at 12.0m. The site with the upper limit of ASS at -1.0m (Table 3) is located 1.5km south of the Barron River and the start of freshwater valley. The site consists of alluvial clay loam to 2.2m, over riverine coarse sands to 6.7m, over ASS clays and sands to 15.5m. Below 15.5m is non ASS riverine material to at least 16.8m. Both of the above sites have undergone a reworking of the ASS deposition by a riverine environment. The site with the upper limit of ASS at 0.2m (Table 3) is located 1.2km south of the Barron River and east of Freshwater Creek. The site consists of predominately mottled clays and fine sands (non-riverine) material to 7.6m AHD over ASS clays to 13.2m AHD. A non-marine pre-Holocene surface was encountered at 13.2m. This site has had no reworking by migrating river channels. The areas that have undergone a reworking of the ASS deposition by a riverine environment are likely to have the upper limit below 0.0m AHD.

Table 3. Upper Reaches Riverine over ASS

	Sites (m) AHD							Average	Median	Standard Deviation
Elevation	6.40	6.70	4.00	5.70	5.30	7.60	4.90	5.9	5.70	1.21
Depth to ASS	6.20	7.10	4.70	6.70	6.80	9.20	7.00	6.8	6.80	1.33
Upper Limit of ASS	0.20	-0.40	-0.70	-1.00	-1.50	-1.60	-2.10	-0.9	-1.00	0.79

Freshwater Creek exits from a valley located to the south of the Barron River delta. The river-dominated environment restricts the likelihood of ASS deposition up the valley to approximately 2.7km from the Barron River. At the margin of the marine influence alternating layers of marine and riverine deposition can be found. Examination of the area above the marine influence found that in a river-dominated environment if ASS was not found before the -1.0m upper height then it was unlikely to found at depth. The migrating river channels and interaction of the riverine environment cause the deposition of ASS in this area to be highly variable.

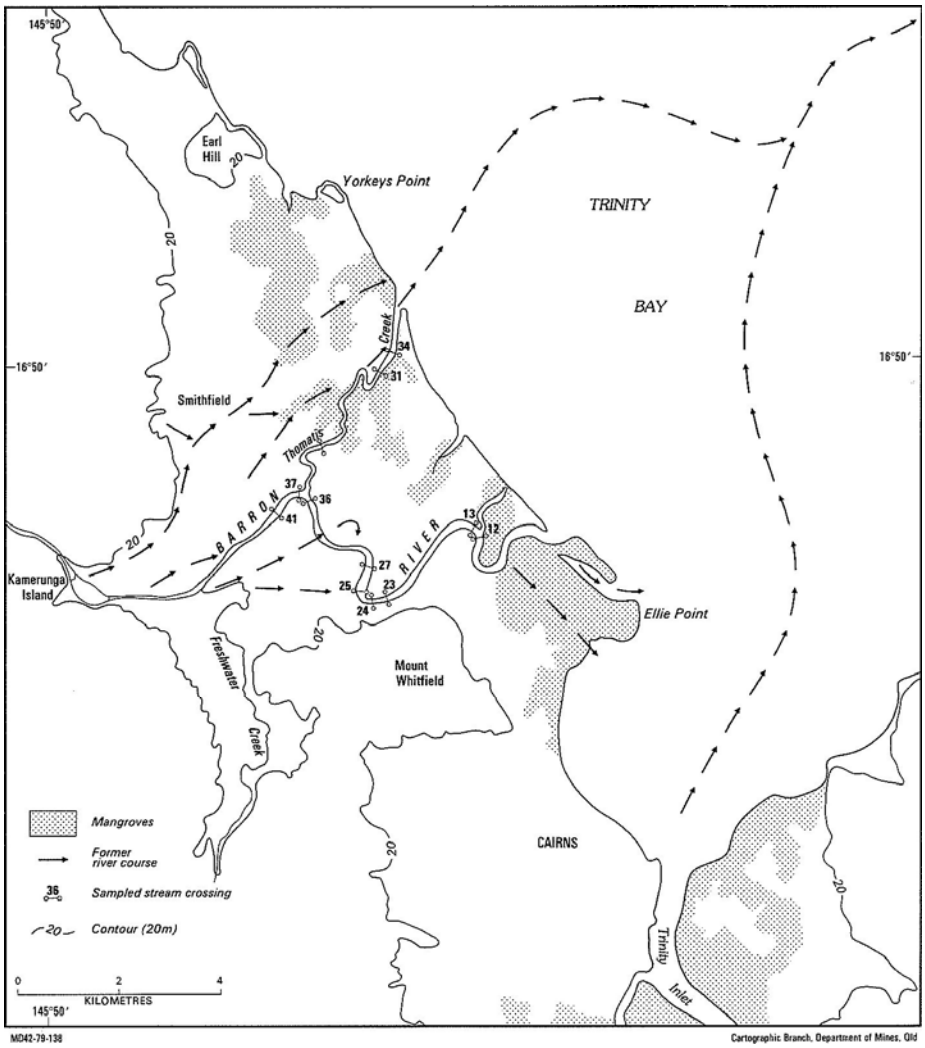

Figure 1. Locations of former river courses. Jones (1985)

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