THE RELATIONSHIP BETWEEN WETTING AND DRYING CYCLES AND PEDAL STRUCTURE, FABRIC AND MINERALOGY AT LOVEDAY LAGOON

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INTRODUCTION

Loveday lagoon is a decommissioned salt disposal basin within a natural wetland. It is immediately adjacent to the Murray River near the township of Cobdogla, South Australia. The lagoon operates as a terminal system, with engineering structures along the western and northern perimeters, and a higher elevation clay ‘plug’ at the southern end, controlling inflow from the river. It is bisected by a causeway through which a series of culverts are located and which can be manipulated to control volumes and flows of water in the northern and southern basins. A regime of wetting and drying has imposed, over time, the development of pedal structures across the wet-dry and into the wet zones of the lagoon. These are a distinctive feature of the site and vary spatially and temporally in their development, (Figure 1).

Figure 1: Pedal structures at Loveday Lagoon.

The pedal structures comprise 2-5 prismatic macropeds (~10 cm wide and 25 cm long), which in turn consist of blocky peds of ~0.5-2 cm diameter. Thin-section analysis also shows that these peds are made up of micropeds with diameter < 1 mm. The boundaries between these fabric elements, together with macropores associated with root channels and jarositic mottles, represent preferential flow paths. The physical properties (including porosity, hydraulic conductivity, fabric and shrink-swell potential) of Loveday Lagoon bottom sediments exert significant controls on the pathways, and hence fluxes, of water and solutes through the sediment matrix.

Biogeoeochemical processes occur by which sulfur, iron and heavy metals are speciated within the sediments, but it is the delivery of these substances in solid and aqueous phases to surface and groundwaters or in gaseous phases to the atmosphere, which generates a range of environmental hazards. By understanding the physical properties, their spatial distribution and their effects on sediment mineralogy, it is possible to inform managers on risks and hazards associated with wetting and drying regimes at this site and the implications for management.

METHODOLOGY

Sediment samples and field measurements were taken from transects in the northern (sites 202-205) and the southern basins (sites 401/1 – 401/9). Samples were collected for bulk density, moisture content and linear shrinkage from the upper 30 cm and from distinct parts of pedal structures where these were well developed.

Soil moisture content was measured and bulk density estimated in the laboratory (Black 1986) from which values for porosity and void ratio were derived. Linear shrinkage was measured in the laboratory using the procedures outlined in Australian Standard AS1289.3.4.1-1995.

The morphology of the pedal structures was defined by measuring changes in elevation above the lagoon surface at a midline cross section. Measurements were taken along the wet-dry and wet zones of the northern and southern transects where pedal structures existed. Field measurements of surface infiltration were taken using a disc permeameter (Perroux & White 1988). At site 410/1, additional measurements were taken at 10 and 30 cm depths because of the distinct characteristics of pedal structures at this site. Undisturbed sediment samples were collected for mineralogical and soil fabric analysis. The samples were allowed to dry, were impregnated with resin and thin-sections were taken along horizontal and vertical planes. *In situ* macropores and those developed during the drying process were noted prior to analysis.

RESULTS AND DISCUSSION

The pedal structures do not occur on the basin perimeters, but their presence starts to emerge where cyclic wetting and drying occurs in accordance with changing water levels in the basin. Analysis of the cross sections of the pedal structures shows that they are minimally developed at the boundary of the dry and wet-dry zone, but steadily increase in elevation above the lagoon bed, reaching an optimal height and form towards the boundary of the wet-dry and wet zones (Figure 2). Closer to the wet zone, the pedal structures start to erode and reduce in elevation, with the location of cracks between macropeds clearly expressed on the surface. By contrast, in the southern basin, the development of pedal structures is spatially limited, and measurements were restricted to two sites at the boundary of the wet-dry and wet zones (Figure 3). This indicates that the formation of pedal structures is closely linked to more frequent wetting and drying cycles and that if such a regime is imposed in the southern basin, then the pedal structures will increase in spatial distribution and form. The development of pedal structures is a function of the shrink-swell potential of the clays. Measurement of linear shrinkage shows trends at a range of scales. Firstly, shrinkage of the sediments increases from the edges to the centre of the pedal structures and, generally, down profile. This suggests that differential shrinkage in the centre of pedal structures will impose shear stresses along vertical axes, and that this will generate heave and the extension of cracks. This is demonstrated by the occurrence of pressure faces and slickensides on the vertical surfaces of the macropeds. Secondly, in the northern basin the sediments can experience high to extreme shrinkage at ~20 cm depth, but in the southern basin, maximum shrinkage occurs in the surface material.

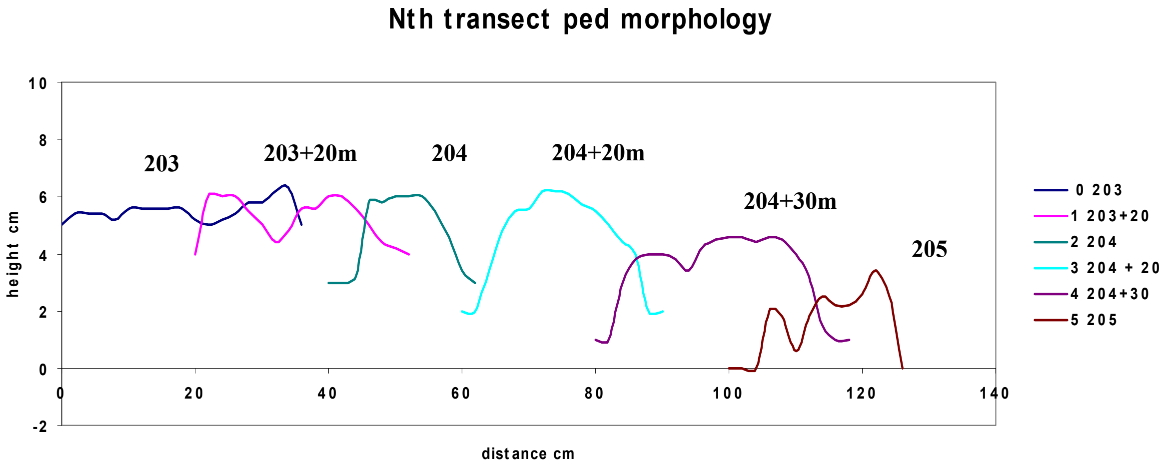

Figure 2: Morphology of pedal structures, sites 203-205, northern basin, Loveday Lagoon.

Measurement of moisture content, bulk density and porosity estimates indicates that, as a first approximation, the bulk density is lower and the porosity higher in the north basin (Table 1). This could be a function of secondary porosity generated by extensive crack systems throughout the sediment matrix, as a result of multiple episodes of wetting and drying, relative to the south side. At a finer scale, it is evident that bulk density generally increases and porosity decreases down-profile, again as a function of the distribution of macropores. However, there is evidence to suggest optimal porosity in material at a depth of 15-25cm at the boundary of the wet-dry zone in the northern basin. This is a site characterised by the disaggregation of macropeds into abundant, highly stable and discrete peds.

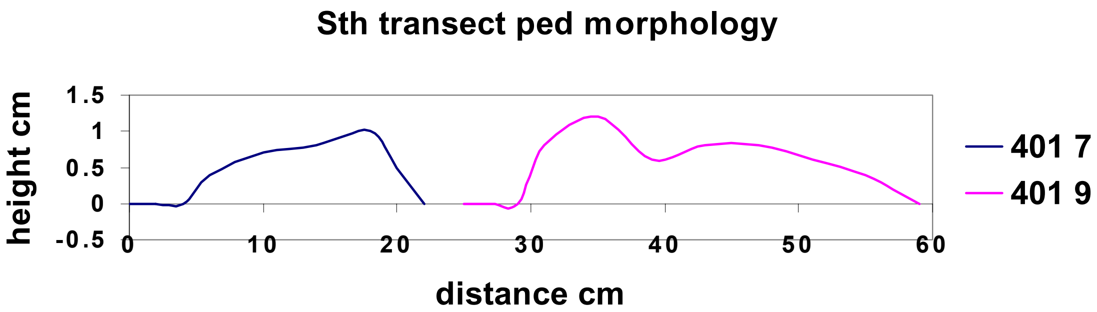

Figure 3: Morphology of pedal structures, sites 401/7 and 401/9, southern basin, Loveday Lagoon.

Table 1: Soil moisture, bulk density and porosity of sediments of the northern and southern transects, Loveday lagoon

Sample	**Moisture Content (%)**	**Bulk Density (g/cc)**	**Porosity**
202 surface	*73.82*	*1.10*	*0.58*
202 10-30	*72.94*	*1.22*	*0.54*
202 30-50	*72.83*	*1.31*	*0.50*
203 surface	**65.04**	**0.97**	**0.64**
203 10 (jarosite)	**64.98**	**1.04**	**0.61**
203 10-30	**68.05**	**1.15**	**0.57**
203 30-50	**74.27**	**1.31**	**0.50**
204 surface	*61.58*	*1.03*	*0.61*
204 ped 10-20	*61.13*	*0.62*	*0.77*
204 30+	*61.18*	*1.00*	*0.62*
205 surf	**64.07**	**1.12**	**0.58**
205 10cm	**59.40**	**0.91**	**0.66**
205 15cm	**47.29**	**0.69**	**0.74**
205 20cm	**40.56**	**0.50**	**0.81**
205 25cm	**51.23**	**0.75**	**0.72**
205 30+cm	**70.05**	**1.21**	**0.54**
204S crack1	*49.43*	*0.69*	*0.74*
204S edge ped 1	*54.08*	*0.81*	*0.69*
204S mid ped1	*58.88*	*0.93*	*0.65*

Infiltration results show a wide range of values that reflect spatial variability across the dry, wet-dry and wet zones, and between the north and south transects (Figures 4 and 5). The trends that emerge in the north transect suggest that the highest infiltration at the sediment-water interface is when the basin is inundated. This coincides with the area characterised by optimal pedal structure development, and in the sandy dry zone sediments along the basin perimeter. By contrast, in the south transect, highest infiltration occurs in the dry zones as a function of the sand infilled cracks surrounding the pedal structures, and is relatively slow across the other zones, although there is an increase across the transect towards the wet zone. Comparison of the two transects indicates infiltration will be slower in the south.

Thin-section analysis shows that the sediment has a porphyric texture with minute quartz, gypsum, diatoms and framboidal pyrite within a dense micromatrix of fine clay. Mica and feldspars are rare. Fine, lenticular gypsum occurs as isolated near-surface aggregates within interpedal cracks, indicative of precipitation from solution. Pyrite framboids are distributed throughout the groundmass. Organic material, as cellulose, is present as decomposing roots and wood fragments, some of which can contain higher concentrations of framboids than the surrounding groundmass.

Staining of the matrix by amorphous iron and manganese oxides and oxyhydroxides is evident along the upper surface of macropeds and peds, in zones immediately adjacent to root channels or interpedal cracks, and along boundaries of micropeds, with hypocoatings of some surfaces. Cracking subparallel to the macroped surface can occur within these stained zones. The cracking is due to exfoliation of material cemented by iron oxides and oxyhydroxides, and differential rates of shrinkage across the pedal structure.

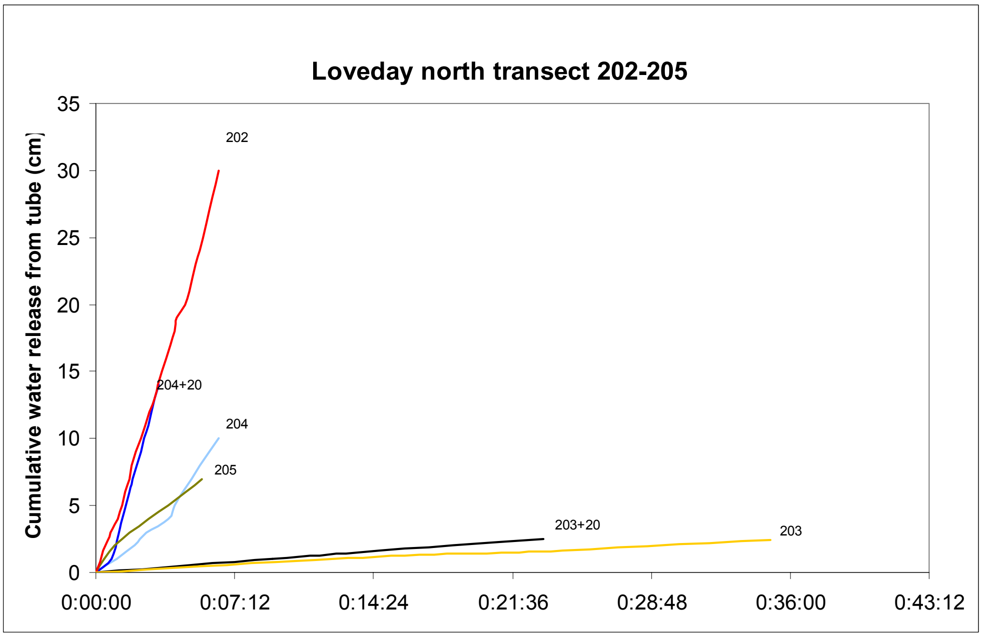

Figure 4: Infiltration responses, sites 202-205, northern basin, Loveday Lagoon. (202=dry zone , 203,203+20, 204,204+20= wet-dry zone and 205=wet zone).

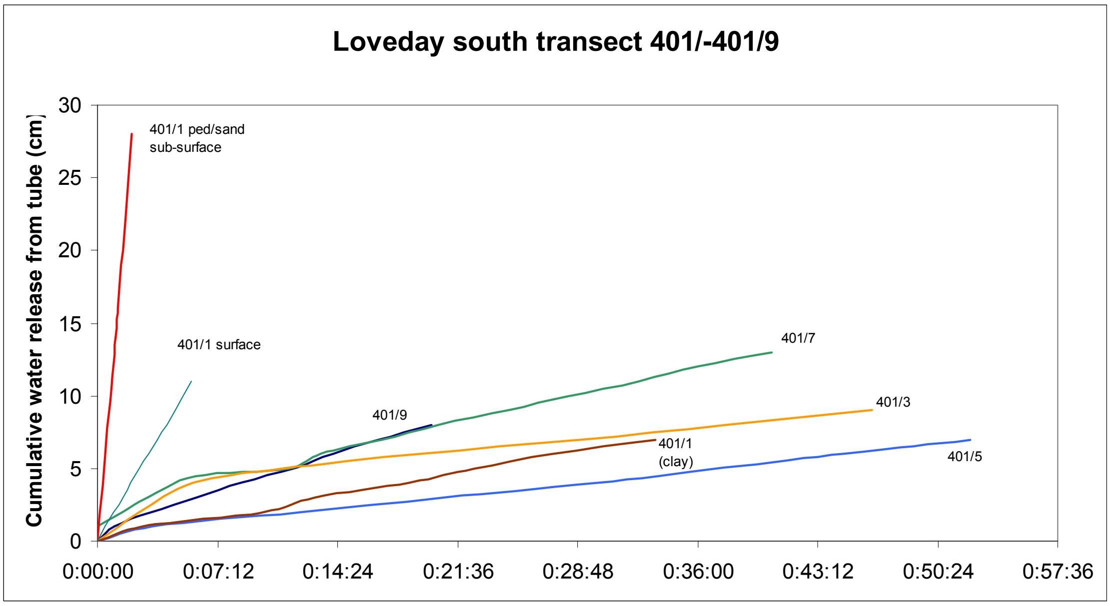

Figure 5: Infiltration responses, sites 401-1 to 401-9, southern basin, Loveday Lagoon. (401-1 = dry zone, 401-3/401-7 = wet-dry zone, 401/9 = wet zone).

The absence of clay coatings along these cracks is a function of shrink-swell behaviour and associated stresses in response to regular wetting-drying cycles.

These physical properties of the bottom sediments of Loveday Lagoon suggest that a more frequent wetting and drying regime in the northern basin has generated highly developed pedal structures that eventually will disintegrate under prolonged inundation. In response to erosion under wet conditions, clay particles and biofilm infill the cracks that separate the pedal structures, and this impedes the rate of solute and water flow along these pathways. The process of wetting and drying, particularly in the presence of differential porosity and shrink-swell potential across and down the peds, imposes movement and shear along discontinuities within the sediment mass. This movement maintains the integrity of planar macropores, and facilitates the flow of water and fluxes of solutes in what is possibly a preferentially vertical direction. The significance of these macropores as preferential flowpaths is evident in the results for infiltration, whereby optimal pedal development is associated with maximum rates of infiltration. Whilst the planar macropores between the macropeds are the major conduits, other discontinuities are also important, as indicated by the spatial distribution of gypsum, pyrite, and Fe and Mn staining along cracks and root channels. It is clear that crack systems at a range of scales facilitate oxidation and the transport of solutes through the sediment matrix. Rates of transport will vary according to continuity, width aperture and length of the cracks.

CONCLUSIONS

The physical properties of the bottom sediments of Loveday Lagoon impose controls on the flow of water into and through the sediments. What is important, for the management of Loveday Lagoon is that a critical frequency or number of wetting-drying cycles appears to correlate with optimal development of pedal structures and their associated macropore systems. Imposing a regime of wetting and drying on the southern basin, where the development of pedal structures is currently limited, may actually increase the area affected by pedal structures and optimise their development. This would increase the fluxes of S and salts with consequent impacts on groundwater and surface water quality. It may also increase the risks of gaseous emissions during drying cycles, when cracks are open and extend to greater depths.

REFERENCES

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