Biogeochemical investigation of the Mt. Gunson minesite and surrounding semi-arid environment.

Daniel Radulovic

Supervisors: Andreas Schmidt-Mumm (Department of Geology and Geophysics).
Petra Marschner (Department of Soil and Water).

School of Earth and Environmental Sciences: University of Adelaide,
Adelaide, SA, 5005, Australia.

A paper submitted in the partial fulfillment of the requirements for an
Honours Degree in the Bachelor of Science.

CONTENTS

Abstract

Near surface mobility and fixation of metals and their effects on plant growth were evaluated at the Mt Gunson tailing dam. The driving force for base metal distribution in the upper metre of the tailings is evaporation and capillary migration. Oxidation and break down of sulphides result in mobilisation of bivalent metals which are concentrated in the upper 40cm of the tailings (having metal concentrations up to four times greater than below 40 cm). Base metals (Cu, Zn, Co and Pb) become mobilised at low pH, resulting in high element concentrations available to plants. Plant experiments on the tailings material showed that the high level of dissolved metals, high salinity and low pH are toxic to all species. Sampling of the adjacent Gunyah Lake and Pernatty Lagoon salt lakes showed that elevated metal concentrations in particular Cu and Pb could be traced within Gunyah Lake but were at background levels beyond 630m from the bund wall of the Mt. Gunson tailings site.

Keywords: Tailings, sulphide oxidation, metal dispersion, salt lake, vegetation.

Introduction

F. Young discovered the Mount Gunson copper deposit in 1875, by identifying outcropping oxidized copper near the present day Main Open Cut (Tonkin & Creelman 1990). Since 1895 mining at the Mt Gunson mine site has been episodic. The last major mining period was between 1974-1976, with the Cattle Grid deposit mined. This resulted in three tailing dams being constructed. Tailings are sand-like waste remaining after valuable metals have been removed from the ore. They are disposed in a liquid slurry and are allowed to dry (Simpson and others 1998). Of particular significance to the Mt Gunson mine tailings are the high metal concentrations still remaining in the tailings. It is important to study biogeochemical processes of the tailings to gain knowledge in the mobility and fixation of metals on a sulphide dominated tailing surface. Oxidation of remnant sulphide minerals decreases the pH of the surface of the tailing, at the same time increasing the bioavailability of certain metals (Morrell and others 1996). These factors are dependent on ore type, grade of ore, buffering capacity of the tailing, potential sulphides and climatic conditions (Borden 2001). Although many studies have been conducted on impacts of mine tailings on ground water, very little research has been conducted to assess the chemical and mineralogical properties of tailings in relation to being a potential use for plant growth mediums (Morrell and others 1996). This has the benefit of increasing understanding of metal mobility and fixation in both the tailing surface and in plants.

Metal distribution from mining activity, though usually on a local scale, remains a global issue (Allan 1997). Elevated metals in ground water, the atmosphere and soil have the potential to spread great distances from a source resulting in health, economic and social implications (Kabata-Pendias & Pendias 1991).

This project will investigate several biogeochemical issues relating to the Mt Gunson mine site. Core samples on the tailing dams will identify distributions and concentrations of minor and major elements and the mineral composition in the upper metre of the tailings. This will serve to understand the surface interactions of elements on tailings in semi-arid regions. A regolith map of the tailings determined whether a relationship exists between landforms and tailing chemical composition. Sampling sediments, below the tailing wall at increasing distances will identify mineral assemblages on the surface. The hydrological input from the tailings (dewatering of tailings) may influence elements available for mineral formation and variation in mineral precipitates. Native plant experiments on the tailing complex and in a controlled environment (glasshouse) identified whether endemic plant species from Mt Gunson are capable of surviving in different soil treatments associated with the tailings. Vegetation surveys identified plants that could be used as future bio-indicators in exploration and for future revegetation programs on the tailing surface. Sediment sampling of the local salt lakes will assist in identifying the dispersion of metals associated with the tailings in the salt lakes. The identification of breaches and potential future breaches along the tailing walls will note locations that may require future monitoring and restoration.

Background Information

Site Description

Mt Gunson mine is located 145 km NNW of Port Augusta, some 55 km SE of Woomera in South Australia, Australia, in a climatic region classified as semi arid. The Mt Gunson deposit is a disseminated copper deposit. Mining has previously been undertaken by open cut method. Waste material from the processing of the ore was disposed of in three tailings that cover an area of approximately 34.25 ha, with a tailing wall height of up to

25m (Puccini, 1996). The tailings are situated near the original historic workings, on the southern side of Gunyah Lake, which is part of the Pernatty Lagoon salt lake. The tailing dams are comprised of approximately 7.4mt. of mined material. The material is fine to medium grained and very quartz rich. The main heavy metals in the tailings are 0.14% (1400 mg/kg) Cu, 250 mg/kg Zn, 200 mg/kg Pb, 140 mg/kg Co, 35 mg/kg Mn and 12 mg/kg Ni in a gangue of quartz and subordinate micas and feldspars (Puccini, 1996).

Regional Geology

The Mt Gunson Mine is located on the Neoproterzoic Stuart Shelf, covering the eastern edge of the Gawler Craton in South Australia (Fig. 1). The mine is located approximately 60km west of the Torrens Hinge Zone, which separates the Stuart Shelf from the Adelaide Geosyncline (Preiss 1987; Tonkin and Creelman 1990). The Mt Gunson deposit is located within the NW trending transcontinental structural G3 corridor, that is marked by an anomalous gravity signature (Preiss 1987). The corridor also encloses the Olympic Dam and Moonta/Wallaroo deposits. Two copper deposit types are seen at Mt Gunson. One hosted in the black shales of the Tapley Hill Formation and the second a sandstone hosted breccia deposit in the Pandura Formation and Whyalla Sandstone. This preceding deposit is known as Cattle Grid (Fig. 2) (Tonkin & Creelman 1990).

Mt. Gunson Geology

Cattle Grid deposit:

The Mt Gunson ore is concentrated in Proterozoic rocks at the contact point between the Whyalla Sandstone and the Pandurra Formation (Preiss 1987). The Pandurra Formation is characterised as being of medium to very coarse grained, poorly sorted, cross-bedded, red bed sandstone with minor mudstone lenses of fluvial origin (braided stream origin). A 150m thick silicified sandstone breccia is found in the upper most member of the Pernatty Culmination (Tonkin & Creelman 1990). The Cattle Grid deposit has the flat lying Pandurra Formation overlain by the Whyalla Sandstone at a disconformity. The Whyalla Sandstone is a medium to very coarse grained, quartz sandstone that is well sorted, with large scale cross-bedding (Lintern and others 1998).

The Cattle Grid deposit is located at the western flank of a north-south trending ridge composed of Pandurra Quartzite and Whyalla Sandstone known as the Pernatty Culmination (Tonkin & Creelman 1990). The mineralisation occurs between the brecciate upper surface of the Pandurra Formation and the Whyalla Sandstone. Sulphide mineralisation resulted in the replacement of pyrite and Cu-Fe sulphides with more Cu rich phases. Precipitation of sulphide minerals infilled fractures and vugs near the surface, as a result of the cupriferous brines moving up along faults and paelosurfaces associated with the Pernatty Culmination (Tonkin & Creelman 1990).

The Cattle Grid deposit consists of a complex sulphide mineral assemblage, that are dominated by chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), bornite (Cu_5FeS_4), pyrite

(FeS_2), sphalerite (ZnS), carrollite ($CuCo_2S_4$), and minor amounts of Ag, Co, Zn, Pb, Ni, Bi and Au are also present (Rattigan 1988).

Cattle Grid was the largest presently known deposit in the Mt Gunson vicinity, that contained 6mt. of ore at an average copper grade of 2.4%.

Cattle Grid Mine History

Extensive exploration over a number of years resulted in the discovery of the Cattle Grid deposit in 1972. This is the largest deposit found during a long history of mining and exploration in the area (refer to appendix I for complete mining history since 1875) (Houston 1977). Cattle Grid is 4 Km south west of the original workings, near Gunyah Lake.

Mining commenced in August 1974. Mining of 6.47 million tonnes of ore and the production 110 000 tonnes of copper and approximately 62 000 kg of silver from Cattle Grid deposit was obtained. The Mt. Gunson mine closed again in August 1984 (PIRSA Internal Report). During this phase of the mine's history, three tailing dams were constructed on the southern side of Gunyah Lake (capacity remaining in tailing three). Mining continued between 1984-1986 under different operators. In March 1989 large summer rains resulted in a breach forming, creating a deep scour channel along the eastern side of tailing three (B.O.M 2002). Research undertaken into the demise of the tailing facility indicated that too much tailings were erratically deposited on the existing tailing 3 facility that altered the designed water drainage pattern. Since 1987 only heap leaching and cementation of copper from Cattle Grid and the Main Open Cut have produced high grade copper cement, which is sent to Burra for conversion to black cupric oxide (Anon 1988). No large scale open cut mining and tailing production has occurred since 1987.

Cattle Grid Mining Operation

The Mount Gunson Cattle Grid ore is located at the interface between the Pandurra Formation and the Whyalla Sandstone. The Cattle Grid deposit was mined by the open cut method. Scrapers and bulldozers removed the overlying waste rock, to within 1 metre of the ore. Then drilling and blasting allowed the host ore to be defined and exposed. The ore was then transported by rear dump trucks to the concentrator 3.5km away (Mt Gunson 1974-1984).

The ore was then crushed from 500 mm in two dimension to less than 25mm, using a Jaques 42” x 30” jaw crusher. Then the ore was ground to 80% less than 200-220μm with the addition of 250g/tonne of zinc sulphate and 250g/tonne of lime. The ore was then rough flotated, with the addition of 5g/tonne of Z-200 collector, at a pH of 10.5. This allowed the removal of bulk gangue. The final scavenger flotation, that involved the addition of 15g/tonne of Z-200 collector, enabled low grade ore and retreated ore to be extracted (PIRSA internal report; Mt Gunson 1974 – 1984).

Three tailing dams were constructed using a down stream design, with tailing walls at 38^0 to horizontal (Fig. 3). The ages of the different tailings are listed in Table 1. The cycloning of coarse grained tailing material formed the tailing walls and resulted in the finer tailing fraction being slurried into the dam.

Climate

The Mt Gunson mine is situated in a climatic region classified as semi arid. The average rainfall is 179 mm per year (B.O.M 2002). Rainfall is usually unpredictable, often intense and interspersed by long periods of near drought conditions. Rains may occur during January/February in the hot season and June/July in the cold season. Evaporation is high at 2400-2500mm during the summer months. Temperature varies considerably throughout the year. During winter months the temperature ranges from 0-20^{0}C, while in the summer the temperature can reach a maximum of 49^{o}C. The average daily temperature fluctuation is around 20^{o}C. Yearly average minimum temperature is 13^{0}C and average maximum temperature is 25^{0}C. Winds for the duration of the year, come from the SE and S, with constant westerly winds during the months of May to July (Warren & Hammond 1984).

Vegetation

Three main types of vegetation communities exist within the vicinity on the Mt Gunson operation.

<u>Gibber Plains or Tablelands</u>: dominated by gibber rocks that are surrounded by vegetation that is classified as low Chenopod scrubland. The Chenopod scrubland is

comprised of Saltbush (*Atriplex spp*.), Blue Bush (*Maireana spp*.) and *Sclerolaena spp*. ground covers, with lack of trees evident.

Red Sand Dunes: are aeolian in origin, and may reach a height of 15 metres. They are dominated by *Acacia aneura* (Mulga) and *A. ligulata* (Sand Hill Wattle). The understorey is dominated by *Dodonaea, Senna, Atriplex and Maireana* species. This community often contains native pines *Callitris columellaris* (White Cypress Pine) on the dune flats, slopes and ridges.

Loam / Sandy Depositional Plains and Flats: support *Acacia papyrocarpa* (Western Myall), Mulga and Saltbush and Blue Bush species. The native pine *C. columellaris* is also present. (Corkin 1984; Warren & Hammond 1984).

Materials and Methods

Core Samples of the three Tailings (upper metre)

A total of 15 one-metre cores on the three tailings were collected. Two samples were collected on tailing one, four samples on tailing two, and nine samples on tailing three. Different number of cores were collected from different tailings due to size variation. A percussion drill soil sampler was used to collect the cores. Once cored, the samples were logged and divided, into different distinct lithological units. Each sample was analysed for minor and several samples were analysed for major element concentrations using

XRF (X-Ray Fluorescence, sample preparation and instrument specifications see appendix). Electrical conductivity (EC) and pH reading in a 1:5 (sample 5g: RO [reverse osmosis] water, 25 ml) ratio was tested for each core sample (refer to appendix I for preparation and instrument specifications).

The average element concentration for Cu, Zn, Co and Pb, pH and conductivity of each core sample were then graphed.

Mineral Identification on Surface Samples

Five surface (top 0.5 cm) samples on tailing 1 were collected and analysed using XRD (X-Ray Diffraction) to identify minerals on the surface of tailing (preparation and machine specification in appendix). One bulk sample (to 1m depth) on tailing three was collected and tested for its mineral composition, near T3.9.

Tailing base samples

Surface samples along two transects perpendicular to the base of tailing three were collected. Distinct differences between surface colouration away from the tailing base were observed. The distance from the tailing and lateral thickness of the coloured units were recorded. The upper 0.5cm of the units were collected and prepared for XRD analysis to determine mineral composition.

Regolith Map of the Mt Gunson Tailings

Field and aerial photo interpretations were applied to produce a ‘regolith’ map of the Mt Gunson tailings and surroundings. Methods and procedures were adopted from the CRC LEME, RTmap Regolith Database Field Book and User Guide, 2nd edition (Pain and others 2000). The same regolith landform units were applied to the tailings, as seen in a conventional regolith environment. Tailing landforms definitions were altered, due to the different environments being represented. A regolith map was produced using ArcView v 3.2a software.

Landforms and core sample locations were compared to identify any relationship between landforms and metal concentration.

Plant Experiments on the Tailing and in the Glasshouse

Mt. Gunson Tailing Experiments

Three plant species endemic to the Mt. Gunson region were used in the plant plot experiments on tailing three. They were: *Atriplex vesicaria* (Bladder Saltbush), *Senna artemisioides ssp. coriacea* (Desert Cassia), *Dodonaea viscosa ssp. angustissima* (Narrow Leaf HopBush). Three replicate plots on tailing three were constructed and fenced, to exclude rabbits (plot dimensions 1×2m facing EW, fencing 1m high). Each of the plots had three treatments (presently there is no vegetation on the tailings).

Treatment 1, tailing material replaced with 40 cm of sand dune material to act as the control medium.

Treatment 2, 7.5cm sand dune material overlaying ploughed tailing material which was limed to increase pH from pH 4-5 to pH 6.5.

Treatment 3, pure tailing ploughed and pH increased to 6.5.

Four plants per species in each treatment were used in the replicate plots.

The plants used in this experiment were purchased from a nursery and were 6 month old, in 200ml pots (with slow release fertiliser added). The experiment ran over a 3 month period (May-July). The plots were watered once a week with a 20 litre container per plot, with 10 litre per m^2. Plant height and health were recorded three times throughout the experiment period. The conclusion of the experiment resulted in randomly selecting one plant per species in each treatment in each plot. Shoots and roots were harvested. Plants were washed in deionised/RO (reverse osmosis) water to remove contaminants. The plants were dried in an oven at 55^oC for 36 hours. The shoots were milled using a mortar and pestle and prepared for ICPAES (Inductively Coupled Plasma Atomic Emission Spectrometry) analysis, using a 70% HNO_3 extract (refer to appendix I for acid extract procedure). All plant results obtained were compared to nursery grown plants, also analysed using ICPAES. The substrates the plants grew in were analysed for total nutrient content using ICPAES (70% nitric acid digest), with two replicates per substrate.

In each of the plant plots on tailing three, seed germination experiments were set up with 10 seeds (non stratified), for each species, per substrate treatment. The plant species were: *Atriplex stipitata* (Bitter Saltbush)*, A. vesicaria, Acacia ligulata, S. artemisioides ssp. coriacea, D. viscosa ssp. angustissima, Enchylaena tomentosa* (Ruby Saltbush)*, Maireana sedifolia* (Pearl Bluebush) and *M. pyramidata* (Black Bush) (Refer to Flora of South Australia for plant descriptions). The seeds were planted 1cm below the substrate surfaces, and watered once a week.

Glasshouse Experiments

Germination experiments of 8 species (same as in field germination experiments) were set up in a glasshouse and planted into seed germination trays. Four treatments were tested.

Treatment 1, sand dune soil

Treatment 2, tailing substrate, at pH 4.5 (natural tailing pH).

Treatment 3, tailing substrate, at pH 6.5, lime added

Treatment 4, tailing substrate, at pH 8, lime added

In each treatment 16 replicates per species (8 stratified seeds and 8 non stratified seeds). The experiment was conducted over a period of one month, watered three times a week with RO water.

The five species used in the pot experiments were: *A. stipitata, A. ligulata, S. artemisioides ssp. coriacea, D. viscosa ssp. angustissima* and *E. tomentosa.* Two hundred stratified seeds per species were sown into trays filled with sand for germination, and watered three times a week for a month.

Seven substrate treatments were used in the glasshouse experiments (Table 2).

Lime was added to tailing material before any mixing with sand dune soil occurred. Pure tailing pH was 4.65 (control). For a pH in the range of 6-7, 2.5 g/kg lime was used to obtain a pH of 6.70. A pH range of 8-9, 150g/kg was required to convert the original tailing pH to 8.25 units.

The soils were potted into 200ml plastic tuber pots. The plants were one month old when transplanted into their corresponding treatment (1 plant per pot). Each of the seven treatments had 12 replicates per species, except for *A. ligulata* only have four replicates, due to insufficient germination. The germinated plants were transferred into their corresponding treatments, and placed in a glasshouse. Plants were watered three times a week with RO water. The experiment was conducted over a three month period (June-September). Throughout the duration of the experiment the condition of the plants and their heights were recorded.

At the conclusion of the experiment all living and non-living plants were harvested (shoots and roots). Living and non-living plants were then separated, cleaned with RO water and dried at 55°C for 36 hours. Above and below ground plant material was milled using a mortar and pestle, and prepared for ICPAES analysis, using a 70% nitric acid digest. All plants in the control treatments were analysed along with live plants in other treatments. *A. stipitata* in each treatments were analysed to determine metal uptake. Approximately six plants of the same species, treatment and condition were analysed together. The soils the plants were cultivated in were prepared for ICPAES analysis using a 70% nitric acid digest, in a 1:10 ratio.

Substrate available elements, in all the soil treatments, in the glasshouse experiments and the field experiments were analysed using ICPAES, with a 0.01M $CaCl_2$ extract, at a 1:10, soil: extractant solution ratio (Houba and others 2000).

Gunyah Lake and Pernatty Lagoon Core Samples

A transect from the north eastern bund (retaining wall, ~2m high and ~4m wide, between mine substrate and Gunyah Lake) in an easterly direction through Gunyah Lake and into Pernatty Lagoon was sampled. The transect was chosen to start on the eastern bund of the tailings complex where copper salt precipitate at the wall and (windblown) sediments, derived from the tailings are deposited on the Gunyah Lake side of the bund wall. Nine, one metre (50mm diameter PVC) pipes were hammered into the playa surfaces, for core collection. Sampling distance from the eastern bund were: 10, 30, 70, 150, 310, 630, 1270 and 2530m along the transect. The last sample was taken 450m south of sample eight to follow the surface drainage flow in Pernatty Lagoon. A distance of approximately 3km (2980 m) was sampled (refer to appendix I for sample location).

The upper 10cm and lower 10cm of each core sample were analysed using XRF major and minor elements, for the elements Cu, Zn, Co and Pb concentrations. Surface and subsurface element concentrations were graphed against distance to determine locations where element concentrations were high.

Vegetation surveys on the Gibber Plains, Revegetation and Sand Dune sites

The surveys on the gibber plains and on the revegetation sites were undertaken in the form of quadrats. The sand dune surveys were conducted in the form of transects on the dunes. Three surveys were conducted in each vegetation community (refer to appendix I for location). Within each quadrat or along each transect plant species, height, position in quadrat or transect and health were recorded. The randomly chosen surveys were done within the vicinity of the mine site.

Gibber Plain surveys were conducted using a 20 × 20m quadrat, with the quadrat facing NS–EW. In a 10 × 10m sub quadrat in the NE corner of the larger quadrat plant species distributions, height and health were recorded. In the remaining portions of the quadrat only abundances of species were recorded. The revegetation quadrats faced NS–EW, and complete species data was recorded throughout the 20×20m quadrat. Transects for the Sand Dune community surveys ran perpendicular (NS) with the dune crests (EW), with vegetation five meters on either side of the transect recorded. Due to limited vegetation on the dunes, all plants along the transect were recorded. Transects surveys were performed over a minimum of three dune crests.

All plants species were identified using the Flora of South Australia (Jessop & Toelken 1986), and Plants of Western New South Wales (Cunningham 1992).

Common species in the vegetation quadrats were plotted, using dimensions of each plant, with Graph pad Prism to illustrate plant distributions throughout the different quadrats sampled, for each species. Average heights for each species was also calculated.

Breaches and Potential Breaches Along the Tailing Walls

Tailing breaches and future potential breaches were recorded using aerial photos and field observations. Regions where erosion caused the upper tailing surface bund wall to collapse was identified as breaching. Those areas where the tailing bund wall was eroding but had not penetrated the bund, were classified as potential future breaches.

Results

Core Samples of the three Tailings (upper metre)

Figure 4 shows locations of core samples on the three tailings. Within the upper metre of the tailings variation in pH, conductivity and element concentrations were measured (Fig 5). As depth increases so does the pH (Fig 5 (a)). Variations are small throughout the upper metre, between 4.5-5.7 units. Electrical Conductivity (Fig. 5(b)) shows extremely high average conductivity concentration (average 10 dS/m) in the top 15 cm of cores and gradually decreases until 40cm depth. Beyond this depth the conductivity remains constant at around 1.5 dS/m.

The comparison of four metals at high concentration on the tailings were graphed (Fig. 5 (c)). Copper was the most abundant metal followed by Zn, Co and Pb.

Copper concentration in the upper 20cm of cores varied. One core showed 20,000 mg/kg copper (2%). With the exclusion of several extreme values the average copper concentration in the upper 15cm was around 5000 mg/kg. Beyond 40cm the copper concentration remains constant at approximately 1200 mg/kg (Fig. 5(d)).

An average of 1700 mg/kg of Zn in the upper 10cm was noted (Fig. 5(e)). Note that $ZnSO_4$ was also added during the ore processing. Concentrations gradually decreased until 40cm. Below 40 cm Zn concentrations became constant at 200 mg/kg. Cobalt shows the same trend as the above two elements having an average upper 10cm of 630 mg/kg, and below 40cm a concentration of 200 mg/kg (Fig 5. (f)). Lead concentrations do not disclose any particular relationship to depth (Fig. 5 (g)). Concentrations are erratic in the upper metre.

No distinct variation between tailing 2 and tailing 3 could be found. Tailing 1 had only two samples cored, both showing varying results, which did not show a clear relationship with the other tailings (Refer to appendix for core descriptions).

Mineral Identification of Surface Samples

Minerals present on the surface of tailing 1 are presented in Table 3. Quartz is the major mineral followed by kaolinite. The XRF major element analysis of three one metre cores on tailing three (3.1, 3.2, 3.3), shows that around 90% of the upper metre of the tailings is comprised of quartz (Table 4). With Al_2O_3 at an average concentration of 5 wt.%, this could account for the kaolinite and muscovite (with the additional 1 wt.% K_20) minerals formed. Halite is also present. Atacamite ($Cu_2Cl(OH)_3$) was also found. This mineral is rare, and Mt Gunson is one of only a few known places in Australia where it can be located.

The major mineral in the upper metre of the tailings is quartz (Table 5). Minor minerals were kaolinite, muscovite, jarosite and atacamite.

Tailing base samples

Quartz is a major mineral followed by halite and gypsum in many of the surface samples at the tailing base (Table 6). Figure 4 shows sampling locations. Some minor minerals could not positively be identified due to limitations in XRD interpretations. The samples in a very wet region at the base of the tailings, S3-S5 also showed large amounts of atacamite present. No distinct mineral pattern from the tailing base was observed from the surface samples that had been collected.

Regolith Map of the Mt Gunson Tailings

An anthropogenic regolith landform map shows the landforms on and in the surrounding vicinity of the tailing complex at Mt. Gunson (see regolith map detached). A regolith map of the tailing surface with core locations plotted illustrates landforms and core associations are shown on Figure 6. [Refer to unit names on detached main regolith map]. Table 7 indicates large variations exist between cores in the same landform units. The result suggests that higher metal concentrations are found in the Afa and Awa regions on the tailing surface, especially for Cu.

Plant Experiments on the Tailing and in the Glasshouse

Mt. Gunson Tailing Experiments

The ICPAES results of element concentration in *A. vesicaria, S. artemisioides ssp. coriacea* and *D. viscosa ssp. angustissima* from the field plots exhibit distinct differences between soil treatments (Fig. 7). The health condition of plants are listed in Table 4.

The average Cu concentration in the plants ranges from 1-20 mg/kg [mg/kg = ppm]. Beyond 20 mg/kg Cu is considered excessive or toxic in plants. Zinc concentrations in plants ranges from 1-100 mg/kg, with excessive or toxicity effects on plants at values greater than 400 mg/kg. Cobalt ranges from 8-100 mg/kg in plants with excessive or toxic concentrations at greater than 100 mg/kg (Table 9). Copper concentration for *A. vesicaria*, and *D. viscosa ssp. angustissima*, grown in nursery soil, are above the average toxicity levels found in plants, whilst *S. artemisioides ssp. coriacea*, is within the typical plant copper concentration (Fig. 7(a)). Table 8 reveals plants in the nursery soil were healthy. Zinc concentrations in the nursery treatment were within the average plant concentration, with *A. vesicaria* having the highest concentration and *S. artemisioides ssp. coriacea* having the lowest Zn concentration (Fig 7 (b)). All species showed low concentrations of Co in the nursery soil, all having a concentration of < 2 mg/kg, the detectable limit of the ICPAES machine (Fig 7 (c)).

The Cu concentration for plants grown in the sand dune material was greater than those in the nursery plants, with *D. viscosa ssp. angustissima* having the highest concentration and *A. vesicaria* having the lowest. Zinc concentrations in plants were higher in the sand dune soil than in the nursery soil. *Atriplex vesicaria* had the highest Zn concentration and *S. artemisioides ssp. coriacea* had the lowest. The Co concentration was low compared to the other two elements, with *A. vesicaria* having the lowest concentration and *D. viscosa ssp. angustissima* the highest in the sand dune treatment. *Atriplex vesicaria* was in a healthy condition while the other two species were in good (*S. artemisioides ssp. coriacea*) and poor (*D. viscosa ssp. angustissima*) condition.

The sand dune/tailing treatment showed *A. vesicaria* alive but in poor condition, whilst the other two species had died. On harvesting the plants, *A. vesicaria* had the greatest lateral root extent in the sand dune soil, whilst the other species had developed few roots. Copper concentrations of plants growing in the sand dune/tailing were double those seen in the sand dune treatment for each species with *D. viscosa ssp. angustissima* having the highest concentration and *S. artemisioides ssp. coriacea* the lowest (Fig. 7(a)). *D. viscosa ssp. angustissima* had the highest Zn concentration while *S. artemisioides ssp. coriacea* had the lowest (Fig. 7(b)). Cobalt concentrations were just above the average range in plants, with *S. artemisioides ssp. coriacea* having the highest and *A. vesicaria* having the lowest concentration (Fig. 7(c)).

In the pure tailings there were no surviving plants. Copper concentrations were greater than in any other treatments, reaching over 900 mg/kg in *D. viscosa ssp. angustissima*, which is over two thirds greater than the other two species, with 570 mg/kg for *A. vesicaria* and 550mg/kg for *S. artemisioides ssp. coriacea* (Fig. 7(a)). Smaller increases were noted for *Atriplex vesicaria*, *S. artemisioides ssp. coriacea*, while *D. viscosa ssp. angustissima* had variable Zn concentrations, being similar to the sand/tailing treatment (Fig. 7 (b)). Cobalt concentrations in plants growing in the tailings were higher than in the other treatments (Fig. 7(c)). *Senna artemisioides ssp. coriacea* had the highest Co concentration, while *A. vesicaria* and *D. viscosa ssp. angustissima* had similar concentrations in the shoots.

Total soil content for Cu, Zn and Co in the vegetation plot soil treatments indicate a trend of lower concentrations in the nursery and sand dune soils to the highest concentration in the pure tailing treatment (Fig. 8). The average Cu concentration in world-wide soils is 100 mg/kg. The average Zn concentration ranges between 10-300 mg/kg, whilst the average Co is 1-40 mg/kg (Table 9). Nursery soil, contains low concentrations of heavy metals (Fig. 8(a)(b)(c)). Sand dune soil has the second lowest concentration of Cu, but the lowest concentration, is Zn and Co. The sand dune/tailing treatment is a 50:50 surface sand dune soil and subsurface tailing soil and therefore has an element concentration between pure sand dune and pure tailing, with an average Cu concentration of 1065 mg/kg, Zn concentration of 425 mg/kg and a Co concentration of 58 mg/kg. The tailing treatment has the highest concentration of Cu, Zn and Co (Fig. 8(a)(b)(c)).

Seed experiments on the tailing plots showed only a limited number of seeds germinated. Germination only occurred in the sand dune treatment. Three *A. stipitata* and three *D. viscosa ssp angustissima* plants germinated in the field.

Glasshouse Experiments

The glasshouse seed germination experiments demonstrated seeds were not able to germinate in the tailing substrates, even if the pH was increased by liming (Table 10). Successful germination was only observed in the sand dune soil. No differences in germination between seeds stratified and those non stratified were noted. *Atriplex stipitata*, and *E. tomentosa* showed almost 100 % success in germination. Germination success is in the following descending order: *D. viscosa ssp. angustissima, A. vesicaria, S. artemisioides ssp. coriacea and A. ligulata. Maireana sedifolia* and *M. pyramidata* lacked successful seed germinations in the sand dune treatment.

The results of the pot experiment indicate that the majority of the plants that survived were those in the pure sand dune treatment (Treatment 1) (Table 2). Several *E. tomentosa* and a few *A. stipitata* plants survived in the treatments that had the overlying layer of sand dune material (Treatment 5, 6, 7). Upon harvesting the plants, roots were only found in the overlying sand. They had not penetrated into the sand dune/tailing substrate. This is supported by the ICPAES analysis of the whole plant that showed similarities to those grown in pure sand dune soils. Plants growing in the 75% tailing and 25% sand dune mixed treatments, at all the pH ranges perished within two weeks after the transplanting of seedlings (Treatment 2, 3 and 4). The majority of plants in the treatments with the upper sand dune soil, died gradually during the experimental period as the plant roots came in contact with the lower sand dune/tailing substrate.

All five plant species in the sand dune treatment were analysed for Cu, Zn and Co concentrations (Fig. 9). *Enchylaena tomentosa* had the highest concentration of Cu at 200 mg/kg (Fig. 9(a)). The remaining species in descending order were *A. stipitata, S.*

artemisioides ssp. coriacea, A. ligulata and *D. viscosa ssp angustissima* the latter with 83 mg/kg Cu. *Atriplex stipitata* had the highest Zn concentration at 132 mg/kg, followed by *A. ligulata*, *D. viscosa ssp. angustissima*, *S. artemisioides ssp. coriacea* and *E. tomentosa* (Fig. 9 (b)). Cobalt concentrations in plants were found to be highest for *A. stipitata*, 35mg/kg (Fig.9 (c)). Following this is *E. tomentosa*, *A. ligulata, S. artemisioides ssp. coriacea* and *D. viscosa ssp. angustissima* at 7 mg/kg.

The analysis of all the A. stipitata plants in the seven treatments, indicated that Cu, Zn and Co had similar trends occurring in the soil treatments (Fig. 10 (a) (b) (c)). The only plants to survive were those growing in the pure sand dune treatment. The remainder of the plants had died during the experiment. Plants grown in the sand dune treatment had the lowest concentrations of Cu and Co, with Zn showing the lowest concentration in treatment 7 (Fig. 10 (a)(b)(c)). Plants in treatments having pH value of 3-4 had the highest concentrations of elements (Treatment 2 and 5). The lowest plant metal concentrations were in the sand dune/tailing treatments at pH values of 8-9 units (treatments 4 and 7). Plants grown in treatments that had the 50% overlying sand dune soil (Treatment 5, 6 and 7) had lower element concentrations than those found in the treatments containing only sand dune/tailing soil.

The comparison between sand dune, sand/tailing and pure tailing soils at different pH showed differences in total element concentrations (Fig. 11). All three elements, Cu, Zn levels and Co displayed similar trends, with low pH treatments having higher element concentrations (Fig. 11 (a) (b) (c)). Nursery and sand dune soils had the lowest concentration of all elements. Total Cu concentration was lowest in the nursery soil whilst Zn and Co concentrations were lowest in the sand dune soil. The highest element concentration for the mixed sand dune/tailing, was measured at pH 3-4, followed by pH 6-7 and pH 8-9, having the lowest element concentration. The pure tailing soils had the same concentration trends as the combined treatments. The pure tailing treatments had higher concentrations than the combined treatments.

Comparisons between total and available elements (Table 11), for Cu, Zn and Co draws attention to the fact that major differences were observed between total element concentrations and those that are presently available to plants. As alluded to in the above sections the nursery and sand dune treatments had the lowest total element concentrations whilst the combined and tailing treatments had the highest concentration of total elements for Cu, Zn and Co. Nursery and sand dune soils had concentrations of available elements that are close to or below the detection limits of the ICPAES, <1 mg/kg for all elements. Pure tailing treatments at different pH levels show that at pH 3-4 (naturally found on the tailing), the available elements almost equalled that of the total element concentration. At pH of 6-7 the available elements are dramatically lower than those above. The pure tailing at pH 8-9, are substantially lower than those from the other pH tailings. The combined sand dune/tailing soils emphasise the same trend as those seen in the pure tailings.

Both soil treatments with pH 3-4 (pure sand dune and combined sand/tailing) showed Cu as the most available element. Whilst at pH 6-7 and pH 8-9, Zn followed by Co had the most available elements accessible to plants.

Gunyah Lake and Pernatty Lagoon Core Samples

Figure 12 shows the location of cores samples in the salt lakes. Electrical conductivity results demonstrated that the first two sample locations had very high EC readings (Fig. 13 (a)). These two samples were in very moist sandy soils with halite crystals evident in the upper 10cm (refer to core logs in the appendix). Elevated EC readings were also observed in the subsurface samples. The remainder of the surface and subsurface samples had constant EC. The surface samples had elevated Cu concentrations at distances of up to 630m from the bund (Fig. 13 (b)). With extreme Cu concentrations at 70 and 310m. The subsurface disclosed high concentrations of Cu to about 70m from the bund wall. Both surface and subsurface readings continually decreased away from the bund. Elevated Zn concentrations were recorded at a distance of up to 150m, with a steady decrease from the bund wall to 150m (Fig.13 (c)). Subsurface concentrations of Zn were elevated to between 70-150m. Beyond 150m the surface and subsurface readings were stable. Cobalt concentrations on the surface were elevated to between 310-630m, whilst the subsurface had elevated readings to about 70m (Fig. 13 (d)). A gradual decrease occurred as the distance from the bund increased. At 2530m a slight increase in Co, 22 mg/kg was found, Pb also showed this trend. Elevated Pb concentrations on the surface up to a distance of 630m was observed (Fig. 13 (e)). The highest concentration was reached at 310m with a concentration of approximately 450 mg/kg. Elevated subsurface Pb concentrations are found at a distance of 30m. Beyond this sample Pb is constant, although increasing slightly at 2530m away from the bund.

Vegetation surveys on the Gibber Plains, Sand Dune and Revegetation sites

Plant species found in the three vegetation communities surveyed are listed in table 12.

Gibber Plains: environment is characterized by gentle, undulating, old peneplain surfaces. Survey localities in Figure 12. The vegetation cover is typically sparse, with an average vegetation cover of 35%, bare 25% and gibber rock cover of 40%. The soil is generally a reddish brown, loam with fine sand composition (5YR4/4), with pH of 7 and EC of 0.12 dS/m. The community is dominated by *A vesicaria* shrubs and several *Sclerolaena* ground cover species, which can be observed in distribution diagrams (Fig. 14). The plants are shown to clump in groups with varying age. This clumping is less evident for *A. stipitata*, but the plants are also close to each other. Many of the *Sclerolaena* species demonstrate clumping.

Revegetation Sites: are on 'dimple' sand dune material (refer to appendix for revegetation technique applied). Revegetation was carried out on the southern side of the Cattle Grid deposit (Fig. 15). The sand 'dimple' soil is predominantly a medium to coarse grain reddish brown (2.5YR4/4) aeolian sand with a pH of 8.5 units and EC of 0.09 dS/m. Seventy percent of the surface is bare ground and 30% contains plants. The dominant species is *D. viscosa ssp. angustissima* (Fig. 15). RV2 has the lowest *D. viscosa ssp. angustissima* abundances. This is due to loss of sand dune material, resulting in *Atriplex fissivalvis* becoming the dominant shrub at RV2. In RV1 and RV3, young *A.*

aneura trees are evident. All trees were in poor condition due to heavy selective grazing by cattle. This species is a dominant plant on the sand dune communities, and is being depressed at revegetation sites.

Sand Dunes: within the Mt Gunson region range from 3-15m high, with an average height of 8m. The dune crests run approximately EW. Sand dunes are not continuous and are interlaced with gibber plains in many areas. The sand dune soil is predominantly medium to coarse grain aeolian sand, reddish brown (2.5YR4/4), with a pH of 6.8 and a EC of 0.03 dS/m. The sand dune communities are dominated by *Acacia papyrocarpa* on dune slopes and crests and *Acacia aneura* on sand dune swales. This community is very open with limited understory plants present. *Enchylaena tomentosa* was the most dominant understory plant, usually growing under the canopy of the acacia trees. Lack of juvenile acacias on the sand dune was observed.

Sand plain and Loam plain communities are also found within the Mt Gunson region, and may contain other species not mentioned in Table 12.

Breaches and Potential Breaches Along the Tailing Walls

Two breaches and five potential breaches were identified (Fig. 4). Breaches 1 and 2 are on the eastern side of tailing three. Potential breaches identified show erosion channelling on the tailing walls. The majority of the potential breaches indicate early stages of erosion. PB5 is the most eroded with an erosion channel approximately 30m wide near the tailing dam surface. On the tailing surface, a slump directly behind the eroding tailing wall had formed.

Discussion

Acidity on the tailings results from the oxidation of sulphides and hydrolysis of metal precipitates, such as hydrolysis of iron (Markos & Bush 1982). Lower down in the tailings less oxidation occurs resulting in the increase in pH (Figure 5(a)). Evaporation dominated processes via capillary action influencing the distribution of elements in the upper surface and oxidised zone. This process greatly influences the chemistry and biochemistry of the tailing (Fig. 16). As evaporation exceeds precipitation the water flow in the tailing changes to an upward migration, via capillary forces. Sulphide oxidation [$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{3+} + 2\ SO_4^{2-} + 2\ H^+$, $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe_2+ + 2SO_4^{2-} + 16H^+$] results in bivalent Fe cations being released. Oxidation of other minerals such as chalcopyrite Cu^{2+}, sphalerite Zn^{2+}, carrolite Co^{2+} and galena Pb^{2+} releases bivalent ions that become mobile and are transferred up to the surface of the tailings. These ions can be transported to the surface in several soluble forms (sulphates, chlorates, silicates and carbonates) (Ritcey 1989). The defining reason for this phenomenon is the evaporative effect of moisture on the tailings. As a result the upper surface becomes dominated by soluble ions and therefore enriched in the upper 20cm of the tailing (Fig 5). Once precipitated the soluble salts and ions accumulate on the upper surface. When precipitation on the tailings occur the soluble fraction dissolves and reprecipitate, when evaporative conditions prevail. Water movement from the base of the tailing into the surrounding environment also influences the precipitation of soluble minerals at the base of the tailings.

The upper metre of the tailing complex shows pH increasing with depth. A gradual increase down to 40cm is due to lowering oxidation of tailing material (Figure 5 (a)). Below this the pH varies, but tends to increase. The EC is highest at the surface as a result of soluble salt precipitation (Figure 5 (b)). Electrical conductivity decreases below 40cm as capillary action and precipitation of salt and ions is less intense. The same trends as EC are also observed for Cu, Zn, Co, but not Pb. This suggests that EC and element concentration is correlated because they are both driven by the evaporative process.

Copper is the main heavy metal found in the upper metre of the tailings (Figure 5 (c)). High copper prices along with extraction methods resulted in some 8-14 wt% loss of extractable copper to the tailings (Mt Gunson 1974 – 1984). Variation in the upper 40cm is associated with the precipitation of Cu from soluble salts. The same trend occurs with Zn and Co, with Co showing a larger variation in concentrations (Fig. 5 (e)(f)). Low Pb concentrations in the samples along with variation in Pb concentrations at certain depth show no defined Pb relationship exists with depth.

Jarosite was evident in the upper metre sample and is known as a scavenger of heavy metal due to a negative mineral charge (Table 5). This could also have aided in the distribution of elements in the upper surface of the tailing. With only one bulk sample analysed and only small amounts identified, the importance of jarosite in the distribution of elements in the upper surface of the tailing cannot be substantiated. Surface minerals present in the upper 0.5cm of the tailing surfaces have quartz as the dominant mineral (Table 3). With the Pandurra Formation and the Whyalla Sandstone containing predominantly quartz this has resulted in the tailings containing around 90% quartz. This was also observed from the bulk sample core, along with the three cores analysed with XRF for major elements. Kaolinite and muscovite are the primary minerals along with halite.

Tailing base, surface samples contain high amounts of quartz, halite, gypsum and atacamite (Table 3). The evaporation and capillary forces of solutes can explain the movement of these minerals to the surface. Evaporation causes the build up of elements on the surface and as a result causes precipitation of the soluble fraction with the associated ions (Ljungberg & Ohlander 2001). The precipitation of atacamite in regions of moist surface is a result of the dissolution of gypsum at a low pH along with availability of Cl^- ions to form atacamite (Williams 1990). Chloride minerals of base metals are known from oxidised zones, especially in arid climates with saline water present (Williams 1990). Moisture content affects the colour and appearance of the sediments due to diffraction properties of minerals (Williams 1990).

In future work the soluble minerals that are associated with the surface of the tailings should be investigated. Soluble minerals were not identified due to the XRD machines capabilities and method used.

The upper metre cores show greater variation, demonstrating higher element concentrations in landform Afa and Awa (Fig. 6). As Afa is the highest feature on the tailings (surrounding the cyclones used in the tailing construction), sediment movement to lower elevations suggest that, this landform is most likely to be affected by oxidation and the evaporative process. Awa also has high metal concentrations because of its ability to store water during wet periods. As a result metals are transported to these locations during wet periods and remain, after the water has evaporated. This is only seen for Cu (Table 7). A likely reason is lower concentrations of other metals. Elevation levels between the different regolith landforms on the tailing surface are less than 2m, and therefore may not necessarily be significant indicators of metal distribution at this scale. Regolith landforms may suggest a reason for the variation in core element concentrations, but other factors such as mineralogy of ore mined and extraction rates may be a major contributor to variations noted.

Metal concentrations, pH and salinity of soil and sediments influence elements that are available to plants (Allan 1997). At low pH solubility and mobility of metals are at their greatest, where as at high pH the majority of metals are insoluble and immobile. At neutral and alkaline pH's, Cu and Co are insoluble and immobile (Wilson 1996). Figure10 shows the concentrations of elements in plants at different substrate pH's. The more acidic the soil substrate the more the metals become mobile, thus available for plant uptake (Kabata-Pendias 2001). The same observations are noted on the tailings with pH being a driving force for the metal availability. Metals have different availability ranges, and this results in different amounts of elements becoming available with changing pH. All elements have the potential to become available, and the unbuffered $CaCl_2$ extractant used simulates the natural solution phase of soils. Therefore this aids in evaluating natural concentrations of elements that are available presently to plants (Houba and others 2000).

Total element variations seen in the combined sand/tailing treatments and the pure tailing treatments at different pH, becoming lower in the combined treatments due to the addition of 25% volume of sand dune soil that had lower element concentrations than the pure tailing substrate (Fig. 11). The lower metal concentrations in the soils with higher pH may be the result of $CaCl_2$ extractant being buffered by the lime, and thus not extracting all metals. Consequently, this results in less extraction of metals, than soils with lower pH. Dilution by lime (up to 15%, for some substrates) may also cause lower total metal concentrations than that in the substrates without lime addition. It should also be noted that mixing of lime and soil substrates may not have been homogeneous and clumps of lime may have been included in the samples analysed. Copper is the least available to plants as the pH increases compared to Zn and Co especially over pH 7. This is the reason for the low Cu concentrations at high pH being available to plants (Simpson and other 1998).

The total and availability metal concentrations for all substrates varied (Table 11). Nursery and sand dune soils have lower total concentrations of Cu, Zn and Co with pH of between 6-8, which is within the tolerant range for most plants with mobility of the metals being lower than those substrates containing tailings (Marschner 1997). The pure tailing and sand dune/tailing have high amounts of available metals due to the high mobility of bivalent Cu, Zn and Co at low pH (Kabata-Pendias & Pendias 1991).

Seventeen elements are known to be essential for all plant survival (Al, B, Br, Cl, Cu, F, Fe, I, Mn, Mo, Ni, Rb, Si, Ti, V, and Zn) (Kabata-Pendias & Pendias 1991; Campbell, 1996; Marschner 1997). Plants have various techniques to take up elements. Absorption by roots is the main pathway for element uptake. Some elements are absorbed passively, while others such as Cu, Zn, and Co are absorbed actively (using metabolic energy). If root cells are biologically or structurally altered, all elements will be absorbed passively. This occurs when concentrations of elements pass the plants physiological threshold (Marschner 1997). Foliar absorption of elements through rain and wind deposition, can also be accumulated by plants, usually being stored in the above ground biomass (Kabata-Pendias 2001). Many factors such as pH, oxidation-reduction state, hydrolysis, competing cations and formation of soluble salts all determine availability of elements and their mobility within plants.

Concentrations of metals in the substrates may explain the poor survival of plants in the experiments, particularly those associated with tailing substrates (refer to appendix I for all elements tested, and relative concentrations to world soils). The field experiments show high absorption of elements in the plants particularly in the tailing treatments which caused plant death as a result of root damage and therefore passive uptake of metals (Figure 2). Nursery plants used as a control for field plants were in healthy condition due to being grown in optimal soil substrate and climatic condition (Table 8). The variability of plant health, in particular in the sand dune treatment for field grown plants indicated that other factors apart from metal concentrations were important. The movement of soluble salts through the sand dune soil from below tailing material and aerial contamination could both explain the poor plant health. Because the above ground biomass was washed with deionised and RO water several times, contaminates on the external surface of the plants were most likely to have been removed. The roots in field plot trials were not analysed owing to the possibility of high contamination risks as substrates can not be completely removed from roots. Plant element concentrations can be correlated to the element concentrations in the tailing treatments (refer to core element concentrations appendix I). Though lime was added to filed plots, leaching of the lime at lower depths could have resulted in the pH returning to its original acidic condition, therefore resulting in greater element mobility of heavy metals.

The plants grown under glasshouse conditions in tailing associated treatments perished. Plants grown in the sand dune treatment in the glasshouse showed lower concentrations of Cu, Zn and Co than field grown plants (sand soil) in which only shoots were analysed (Figure 7, Figure 8). *Atriplex vesicaria* was substituted for *A. stipitata* in the glasshouse experiments because of insufficient germination. A possible reason for the high concentration in the field may be the movement of soluble salts into the sand dune soil from the below tailings, thus precipitating more metals into the soil. Contaminants via wind movement deposited on the above ground plant material could be a further factor, although the samples were washed prior to analysis. *Atriplex stipitata* grown on the sand dune soil in the glasshouse contains the high concentrations of Cu, Zn and Co. *Enchylaena tomentosa* contained the greatest concentration of Cu, *A. ligulata* was characterised by high concentrations of Zn, however, none of the species were hyperaccumulators (none survived the tailing treatments). Hyperaccumulators are plants that have an above ground concentration of greater than 1000 mg/kg for Cu and Co and

Zn concentrations in excess of 10 000 mg/kg (Greger, 1999). Identifying tolerant plants is difficult due to large variations of metal concentrations between species and even within species (Kabata-Pendias & Pendias 1991; Marschner 1997). *Atriplex stipitata* could be a tolerant plant to many of the metals tested as it shows a higher metal concentration than the other species. Tolerant plants usually contain high concentrations of metals in the roots (McLaughlin and others 2000). Due to insufficient plant biomass from the glasshouse grown plants, entire plants were analysed. Roots typically contain larger amounts of heavy metals than in shoots. This indicates that the glasshouse grown plants may contain lower amounts of metals in the shoots than those measured in the whole plants (Marschner 1997; Kabata-Pendias & Pendias 1991).

The success in seed germination in the sand dune treatment under optimal conditions indicate the suitability of the sand dune soil for plant germination (Table 10). Harsh field conditions, high temperature variations and limited moisture are causes for low field success. Stratified and non stratified seed germinations were similar under optimal conditions. *Maireana spp*. possibly did not germinate due to not having the correct germinating procedure (smoke, fire, etc). Little is known about germination of *Maireana spp.* (Langkamp 1987). The majority of endemic plants from the Mt Gunson region are likely to germinate in a sand dune topsoil, under favourable conditions. This is supported from studies at Mt Gunson, of the revegetation sites which showed many species having germinated successfully after sufficient rainfalls (Mt Gunson 1974 – 1984). The concentrations of heavy metals, temperature variation, moisture variation, lack of mycorrhiza associations and low availability of plant nutrients (refer to appendix I for all elements tested, and relative concentrations to world soils) may be factors associated to the failure of seeds to germinate in tailing treatments in both field and glasshouse experiments.

Element mobilisation and fixation in the upper metre of the tailing is greatly influenced by the evaporative process. This has a compounding effect on plants. Heavy metals on the tailing surface, in conjunction with high salinity levels in the upper 20cm of the tailings resulted in the death of the plants. The EC reading in excess of 0.49 (dS/m), and the tailing natural pH being less than the tolerant levels by plants, pH 5.5-8.5, these factors all contributed to the lack of plant growth and survival to the tailings and combined substrates. Although the pH was increased in certain substrates, available elements concentrations remained high.

Another aspect of this project was to evaluate the metal dispersion in Gunyah Lake and Pernatty Lagoon as a result of previous mining activity. Metal concentrations decreased away from the tailing complex, which was the result of water and wind movement (Fig. 13). Subsurface concentrations are low and this suggests metals are being transported on the surface of the salt lake. Elevated metal concentrations did not exceed 630 metres from the bund, P6 (Fig. 12). Metal accumulation in Gunyah Lake are not necessarily a result of the present breach at the eastern bund wall. Mining in Gunyah Lake throughout the last century could have contributed to the high metal concentrations measured. High concentrations of metals may be a natural phenomena due to previous ore deposits in Gunyah Lake. Previous tailing spills from the breach on tailing three or the run off from tailing material into the salt lake from the original tailing dam could all have contributed to the elevated elements within the vicinity of the bund wall (Fig. 17). Regardless of the source, metal contamination on the southern side of Gunyah Lake is evident. Elevated concentrations of metals appear to be localised within Gunyah Lake. The higher subsurface Pb and Co concentrations although small, may represent natural concentrations found in the rocky unit cored (refer to salt lake cores, appendix I) (Figure 13 (d) (e)). A more thorough sampling regime should be implemented to determine the full extent of the element distribution in the two salt lakes.

The vegetation surveys specify the dominant species present and state the distribution abundance of the species (Figure 14, Figure 15). The distribution of species in the surveyed quadrats show that plants are not evenly distributed throughout an environment, but are found in clusters. The dominance of *A. vesicaria*, *D. viscosa ssp. angustissima*, *A. papyrocarpa* and *A. aneura* should be investigated for potential bio-indicator species of metals. Therefore, this can be adapted for use as an exploration tool in regions lacking outcrop. The most useful species would be those found in a chenopod shrub land, loam flats or sand dune plains. Those species found on aeolian sand dune may be less desirable arising from a lack of interaction with the lower stratigraphic units.

Tailing evaluation suggests that breaches 1 and 2 are of concern, due to continuous loss of tailing material during high rainfall events (Fig. 4). If significant rainfall occurs, (usually every 10 yrs) in the near future the complete failure of the eastern portion of tailing three could greatly influence the stability of the tailing and therefore result in tailing material being deposited in the surrounding environment. PB5 is the most likely location for a new breach. Amid the centralisation of PB5 on the tailings a breach would result in large quantities of tailing material being displaced. Professor Jewell suggested structural stabilisation strategies in 1996 in relation to tailing three (Puccini 1996). For the present time regular monitoring of the tailing walls and breaches should continue.

Conclusions

1. The dominant force influencing the distribution of elements in the upper surface and oxidised zones is an evaporative dominated process via capillary action. Oxidisation of minerals result in bivalent metals becoming mobile. The oxidation process also results in a pH decrease. The movement of soluble ions via capillary action and the precipitation of these ions in the upper 40cm results in elevated EC and metal concentrations at the tailing surface.
2. Regolith landform associated with metal concentrations on tailing cores indicate that a correlation may exist and Afa and Awa having high Cu concentrations with Apd and Aer having lower concentrations. However the large variations of other metal concentrations within landform units, contradict such a relationship. Regolith landforms suggest a reason for the variation in core element concentrations, but other factors such as mineralogy and extraction rates of ore mined could possibly be major contributors to variations in metal concentrations noted.

3. Metal concentrations and mobility, pH and salinity in the soil and sediments influence elements that are available to plants. At low pH solubility and mobility of metals are at their greatest, whilst at high pH the majority of metals are insoluble and immobile.

4. The plant experiments have shown that plants cannot grow in tailings substrates, due to excessive concentration of available metals and high salt concentrations. Plant survival in the sand dune treatment indicate that many of the plant species tested are moderately tolerant to certain metals. *Atriplex stipitata* contains high concentrations of Cu, Zn and Co. Therefore it may have a potential as a bio-indicator plant in exploration.

5. Salt lake sampling has identified elevated metal concentrations of Cu, Pb, Zn and Co on the salt lake surface, with high metal concentrations, in particular Cu. Beyond 630m metal concentrations remain at background concentrations. Elevation concentrations remain localised within Gunyah Lake.

6. Vegetation surveys have identified the Gibber Plains, Revegetation and Sand Dune communities are characterised by different species. The dominance of *A. vesicaria*, *D. viscosa ssp. angustissima*, *A. papyrocarpa* and *A. aneura* in their respective communities should be investigated for potential bio-indicator species. This could be adapted as an exploration tool in regions lacking outcrop. The most useful species would be those found in a chenopod shrub land, loam flats or sand dune plains.

7. The eastern side of tailing three has two breaches which are contributing to the loss of tailing material during periods of high rainfall. A potential breach on the northern slope of tailing three has the potential of destabilising tailing three. Monitoring of tailing walls should continue, especially after periods of high rainfall.

Addendum

Plant experiments specify that no endemic plants are able to survive on the tailings. For successful plant establishment on the mine tailing surfaces capping using bentonite or an impermeable clay, to limit salt and metal transfer up into the top soil should be considered (Williams 1995). Capping the tailing surface will also limit the diffusion of oxygen and the infiltration of rainfall, therefore reducing acidic seepage during rainfall periods. A topsoil cover, of a mixture of sand dune and clay material of 0.5-1.0 m with a sufficient capping of about 0.3m would be adequate for establishing a chenopod shrub land community (saltbush and bluebush species) (Williams, 1995). Revegetation sites surveyed show that the tree *D. viscosa ssp. angustissima* although classified as a weed in New South Wales pastoral and grazing regions is a suitable plant for rehabilitation due to the nitrogen fixation properties of the plant (Cunningham 1992). This species would only be adequate if greater depth of topsoil is used. The sand and clay material that make up natural sand dunes can be sourced from a dune field approximately 600m NW of tailing one. Natural recruitment, aided by direct seeding would be sufficient for successful plant establishment after a sufficient period of rainfall (Osborne 2000). Seed trials demonstrated that suitable germinating conditions are required for a positive response. Prevention of wind erosion of surface soil should be considered. Revegetation trials on tailing 1 bund wall and on the old tailings were conducted during the late 1970s and early 1980s all failing owing to wind blowing valuable top soil away (Mt Gunson 1974-1984). The use of the 'dimple' method in constructing stable topsoil could be adapted. Tailing walls range from 20-38^0 horizontal. Encapsulating the walls with a covering of non-acid generating rock material will help stabilise the wall, encourage vegetation establishment and prevent any rainfall interacting with the potential acid forming tailing material. Any revegetation initiative should only be conducted in association with works related to the stability of the tailings. The stability of the tailing complex is of greater importance and should precede all other work, in relation to the tailing complex.

Acknowledgments

Special thanks to CRC LEME (Cooperative Research Centre for Landscape Environments and Mineral Exploration) for financing this project. Thanks to PIRSA (Primary Industries and Resources South Australia) for providing maps and information, (Olando Puccini and John Ragless). Thanks to Gunson Resources and ADCAM for access to the mine and A & M J Musolino Pty Ltd. for providing accommodation, watering field plants. Thanks to the mine manager Dennis O'Callaghan for assistance. Special thanks to my supervisors Andreas Schmidt-Mumm and Petra Marschner. Field assistance from Karen Hulme, Sean Mahoney and Carly Chor was greatly appreciated. Jose Facelli aided in vegetation survey analysis and plant identification along with John Conran and Russ Sinclair. Finally I would like to thank John Stanley and Colin Rivers for aiding in sample preparation and analysis.

Figures and Tables

Captions

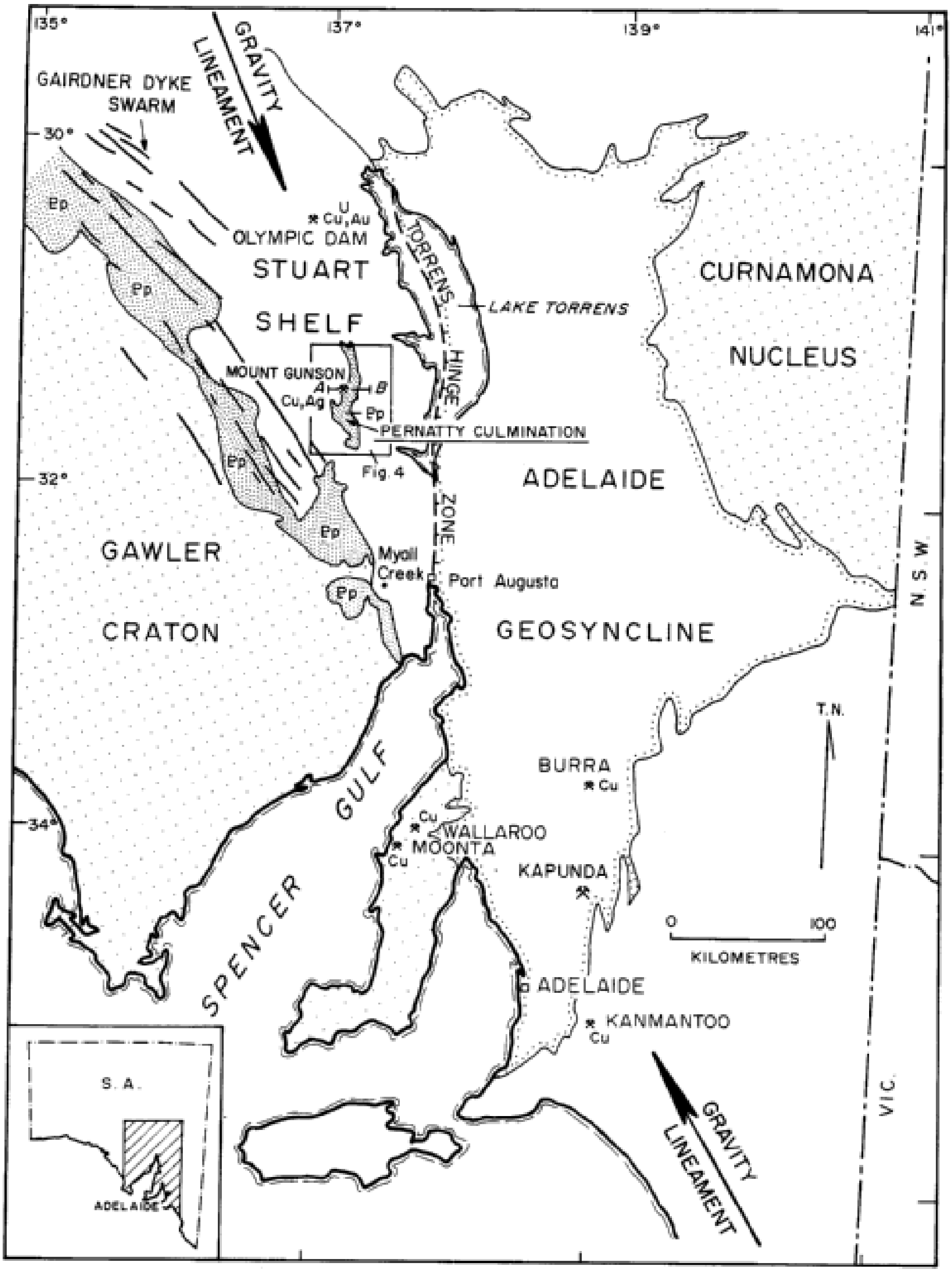


Figure 1: Regional map of the Mount Gunson setting (Tonkin & Creelman 1990)

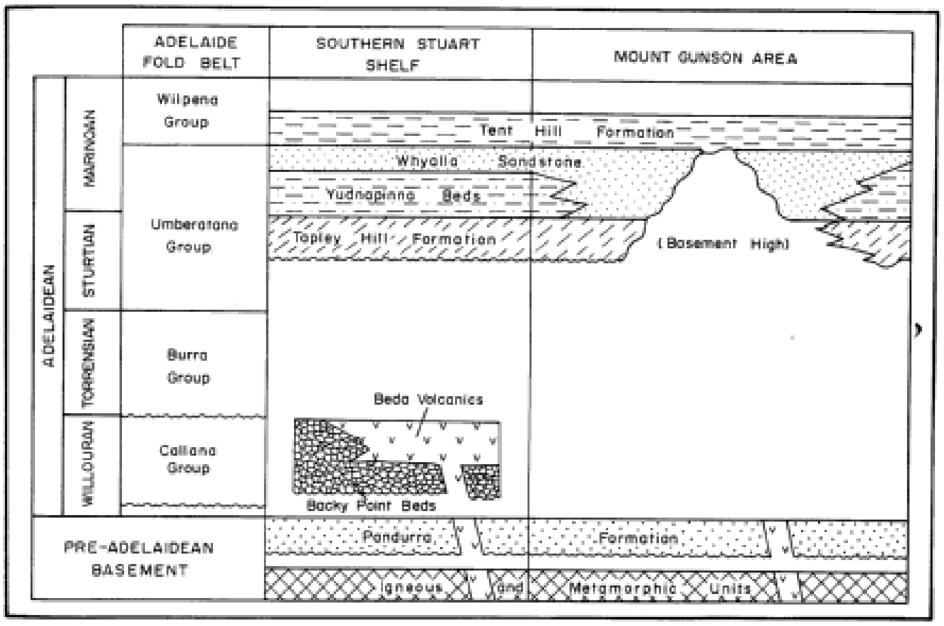


Figure 2: Geological section through the Mt Gunson area. Pernatty Culmination represented by the basement high.

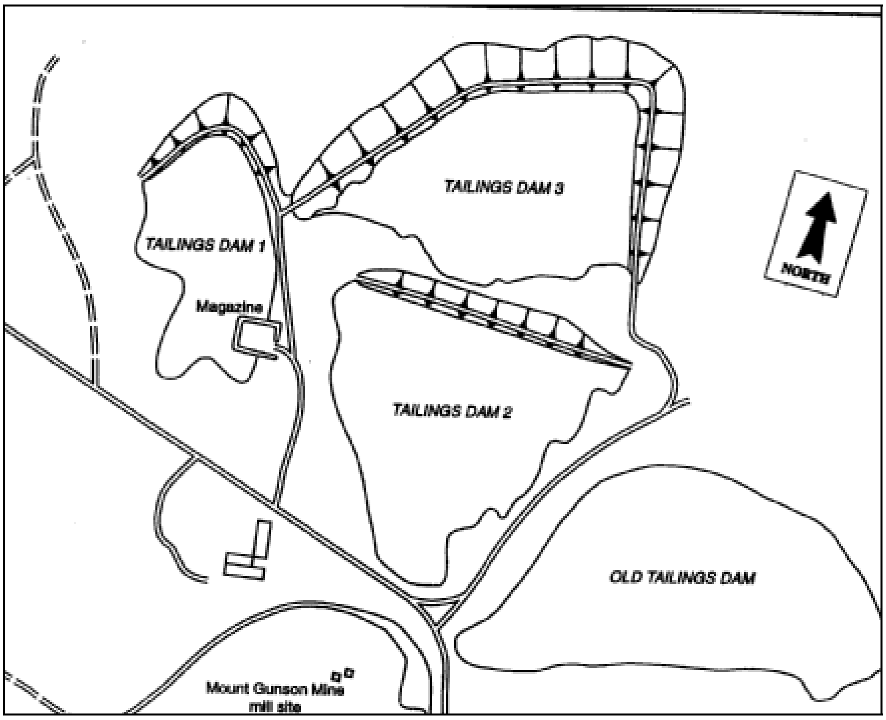


Figure 3: Outline of the tailing dams (Puccini 1996)

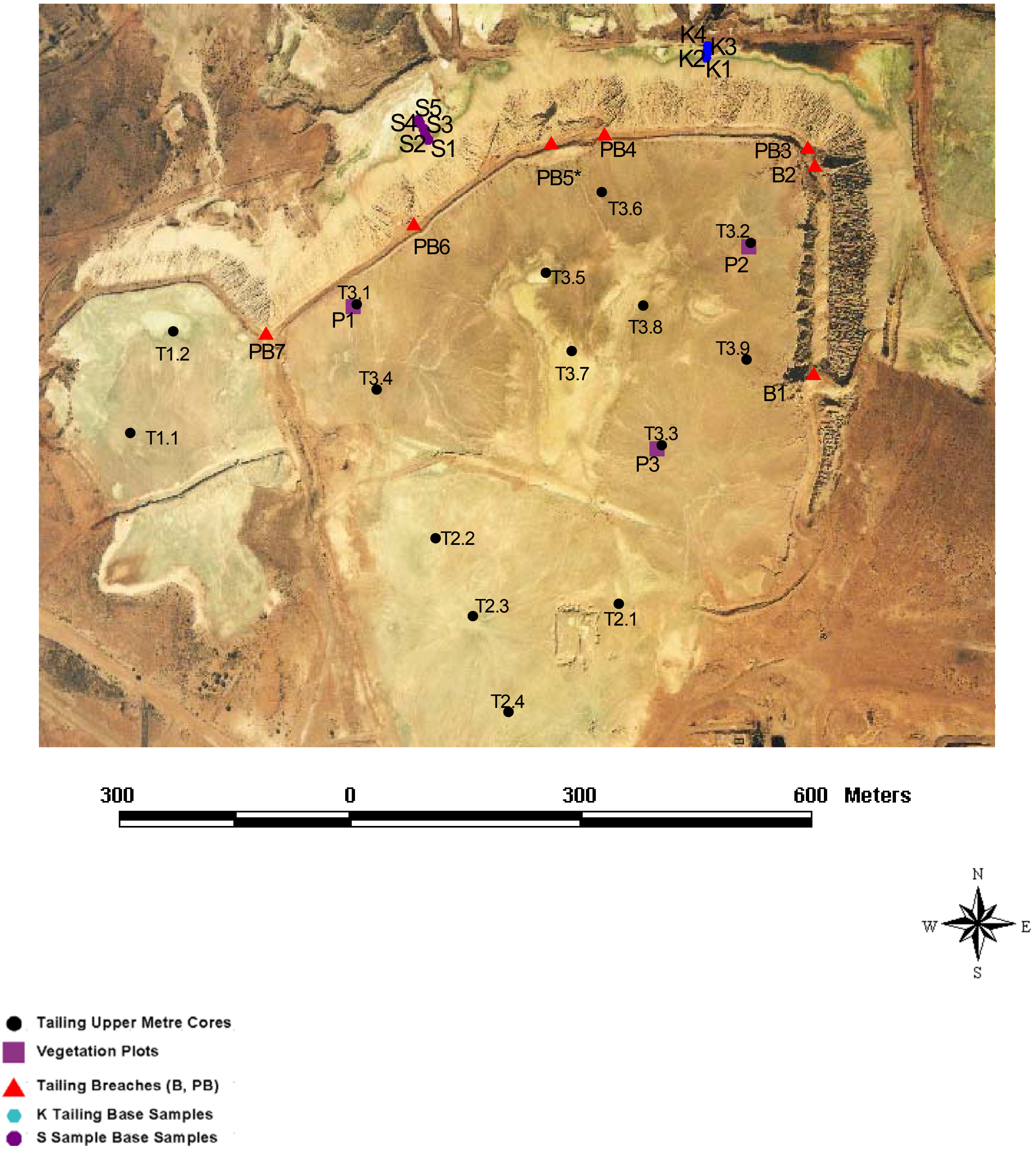
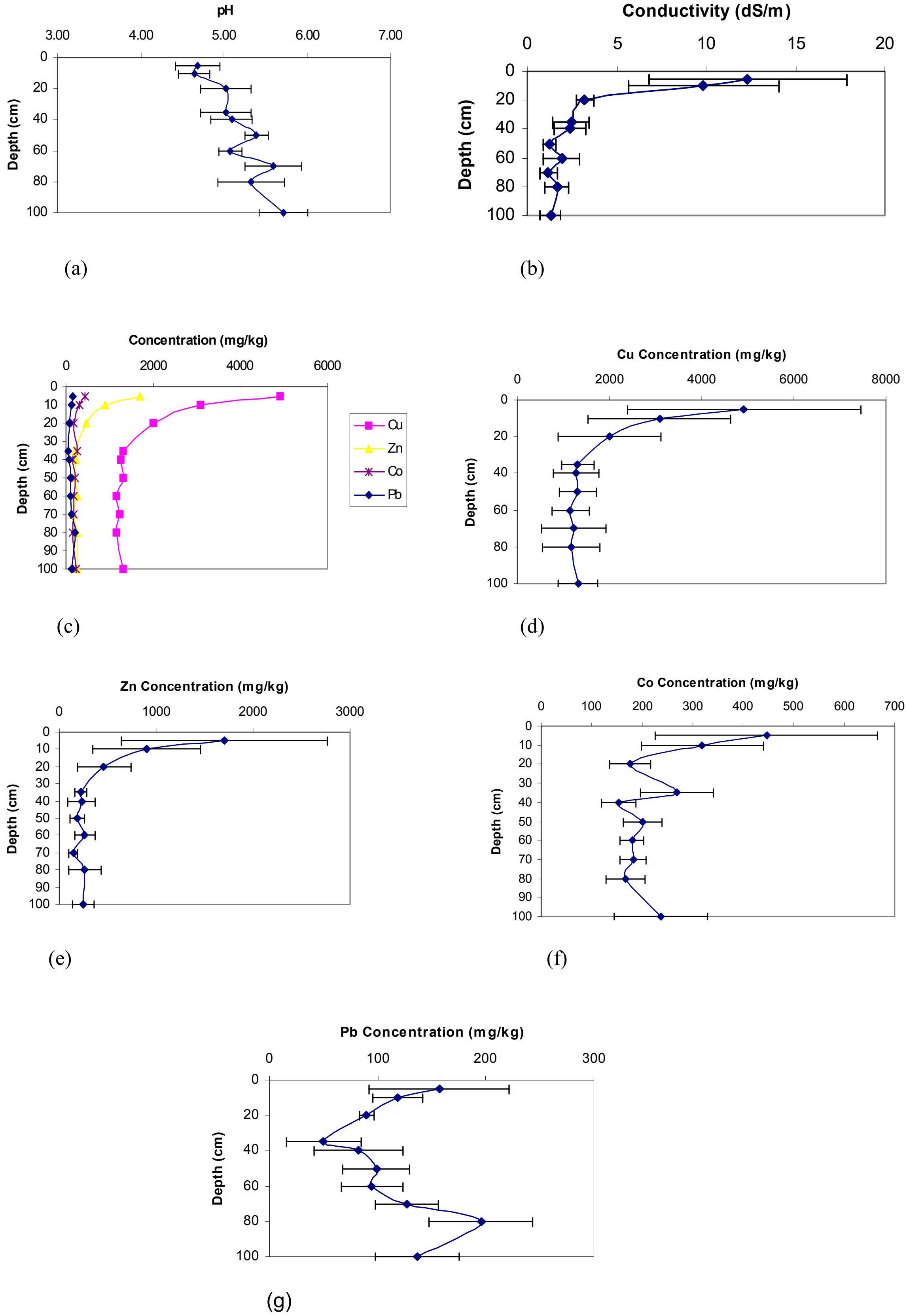


Figure 4: Sampling and Observational points on the tailing surface and below the tailings. T1.1-3.9 are 1 metre cores. P1-3 are vegetation plots on tailing three. B1-B2 are breaches identified on the tailings. PB3-PB7 are potential future breaches. K1-4 and S1-5 are surface samples, below the tailings.



(a) (b) (c) (d) (e) (f) (g)

Figure 5: Graphs representing average pH, conductivity and element concentrations against depth, with 15, one metre cores sampled over three tailings. Standard deviation bars on selected graphs. (a) Average pH vs. depth of tailing cores. (b) Average conductivity vs. depth. (c) Comparative graph of average copper, zinc, cobalt and lead concentrations vs. depth. (d) Average copper concentrations vs. depth. (e) Average zinc concentration vs. depth. (f) Average cobalt concentrations vs. depth. (g) Average Lead concentration vs. depth.

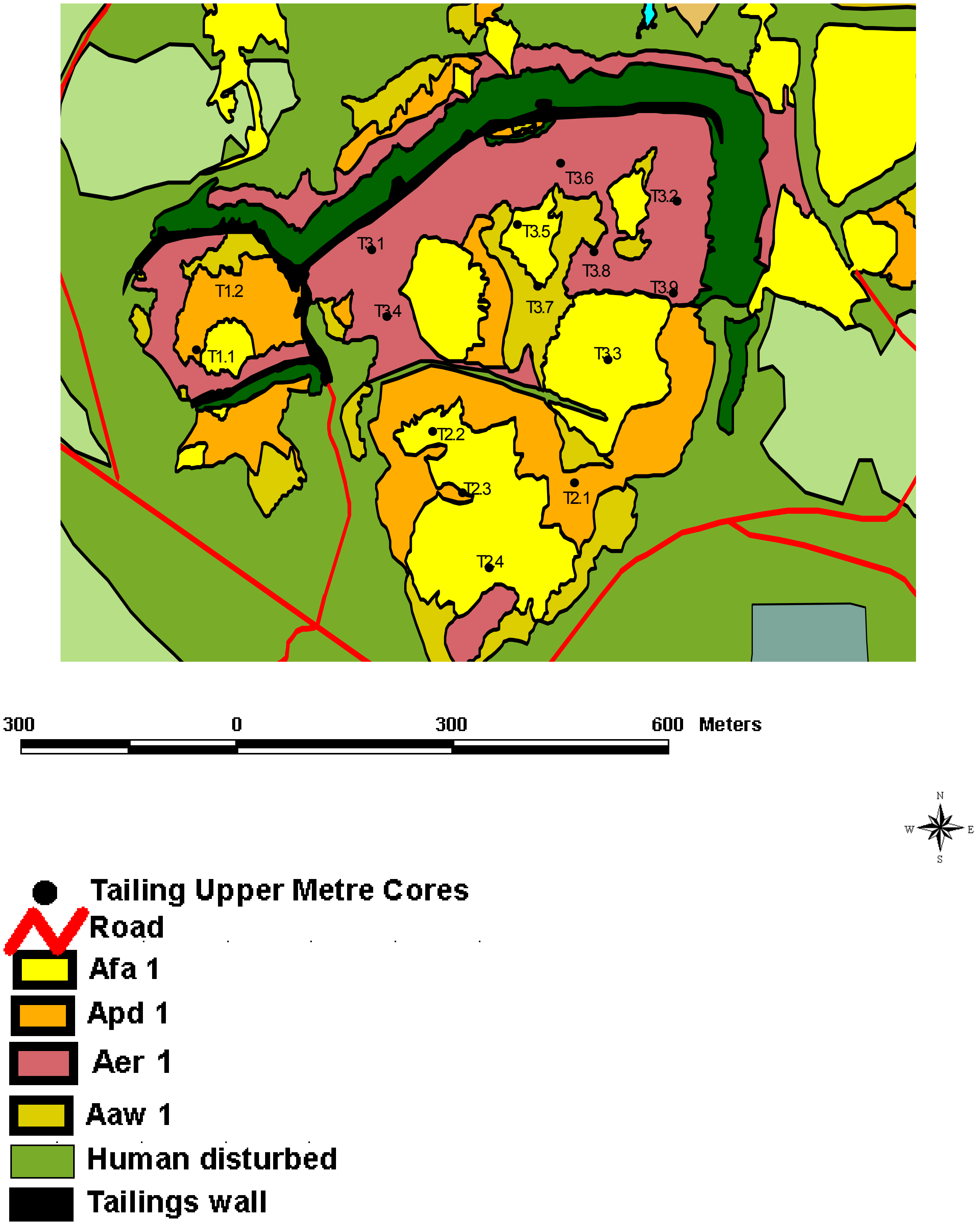
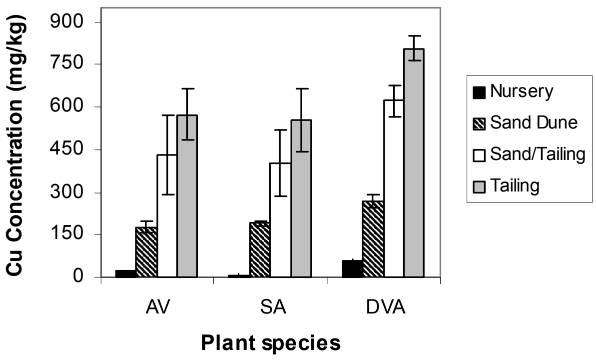
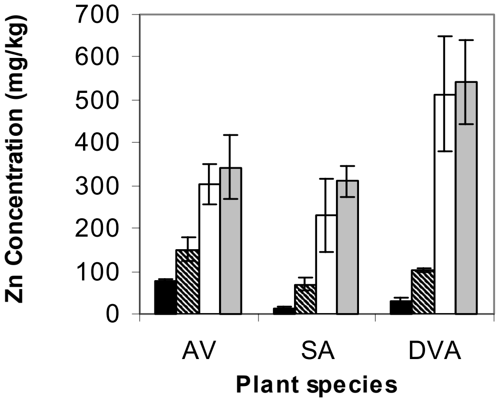


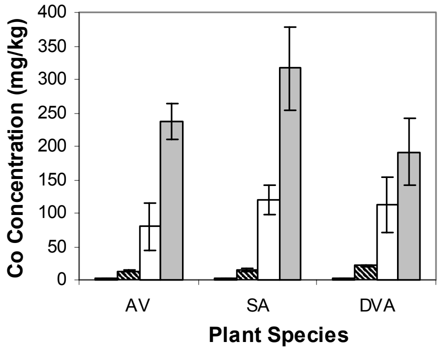
Figure 6: Cores locations and regolith landforms on the tailing surface. Refer to attached regolith map for legend descriptions.



(a)



(b)



(c)

Figure 7: Plants from the Mt Gunson tailing plots. Concentrations of Cu, Zn and Co in *Atriplex vesicaria, Senna artemisioides ssp. coriacea* and *Dodonaea viscosa ssp. angustissima* plants (n=3). (a) Total Cu concentration in the three plant species. (b) Total Zn concentration in the three plant species. (c) Total Co concentration in the three plant species. AV= *Atriplex vesicaria,* SA= *Senna artemisioides ssp. coriacea,* DVA= *Dodonaea viscosa ssp angustissima.* All plant readings are given in mg/kg which is equivalent to ppm. All result are given as dry weights (DW).

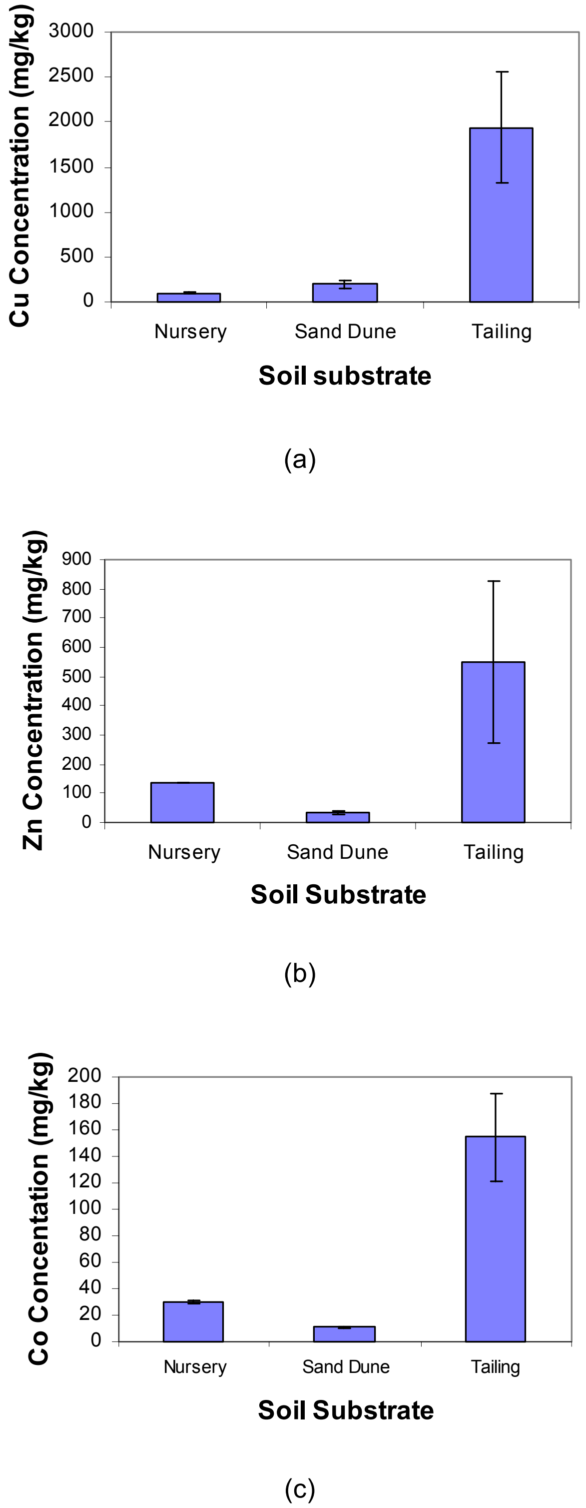
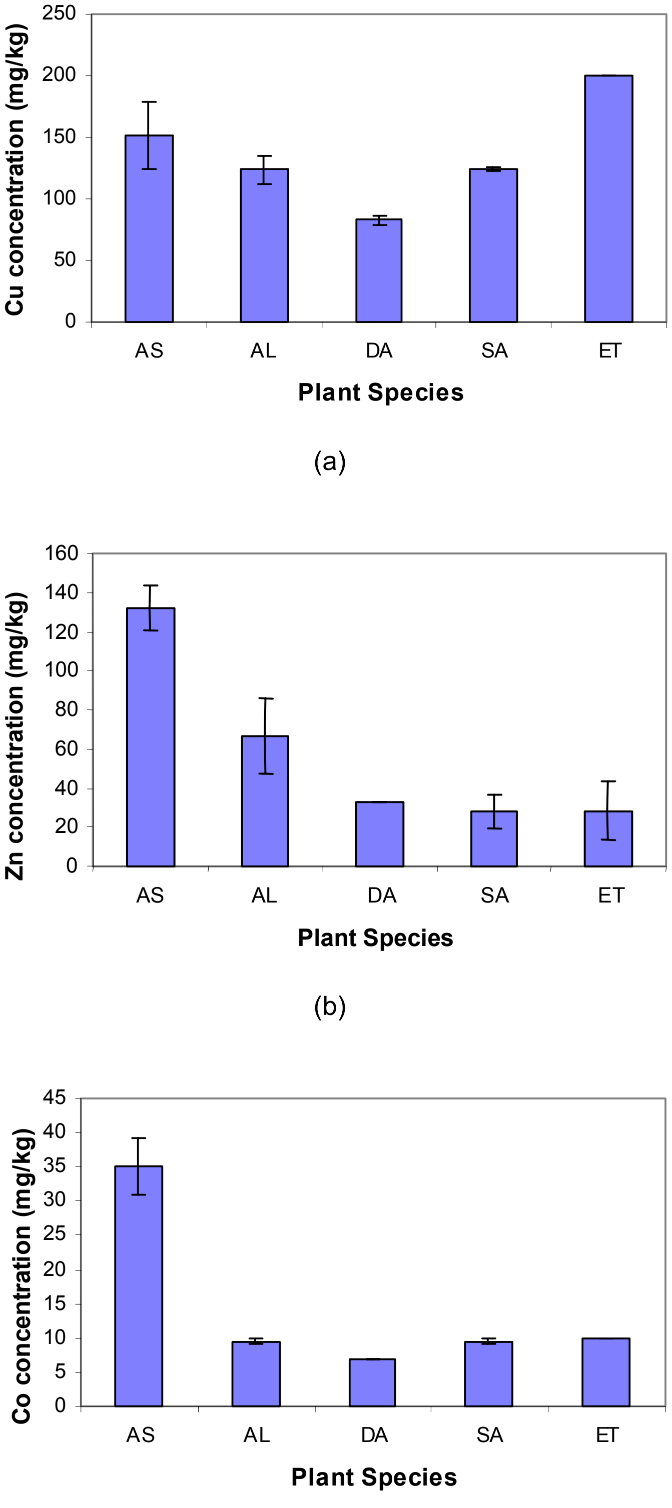


Figure 8: Total soil substrate metal concentration for copper, zinc and cobalt in the field soil treatments related to the tailing vegetation plots. (a) Total copper concentration in the field soil treatments. (b) Total zinc concentration in the field soil treatments. (c) Total cobalt concentration in the field soil treatments.



(a)

(b)

(c)

Figure 9: Total plant metal concentration of Cu, Zn and Co, in the sand dune treatment (treatment 1). (a) Total Cu in the five plant species grown in sand dune soil. (b) Total Zn concentration in the five plant species grown in sand dune soil. (c) Total Co concentration in the five plant species grown in sand dune soil. AS = Atriplex stipitata, AL = *Acacia ligulata*, DA = *D. viscosa ssp. angustissima*, SA = *S. artemisioides ssp. coriacea*, ET= *Enchylaena tomentosa*. Standard Deviation bars inserted to show variability within a species (n = 2).

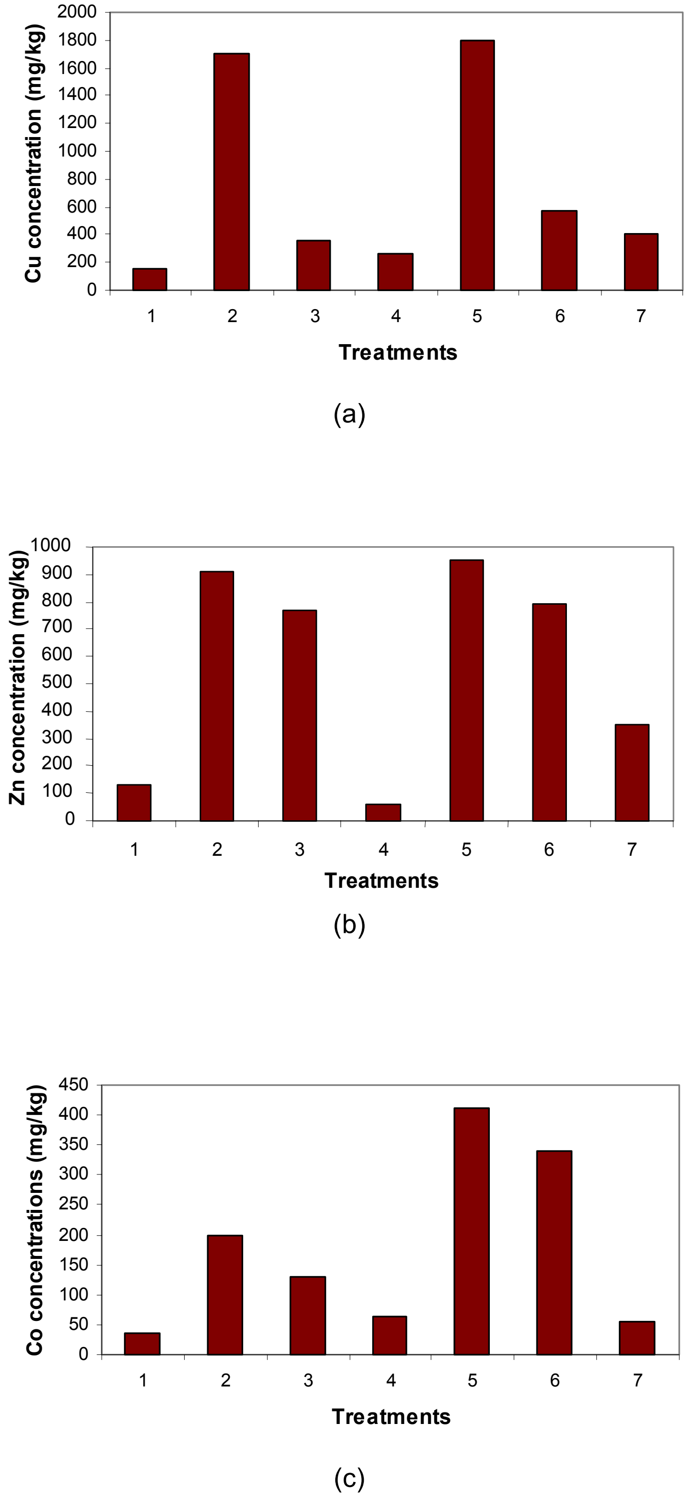
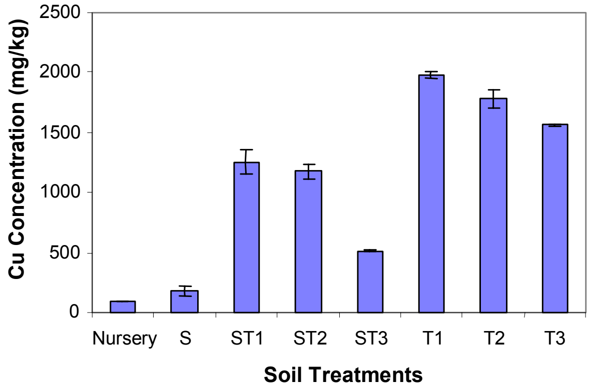
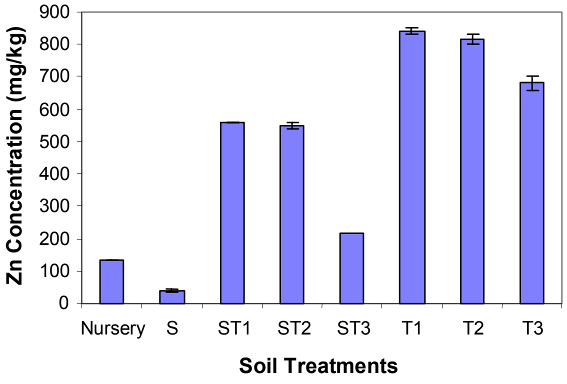


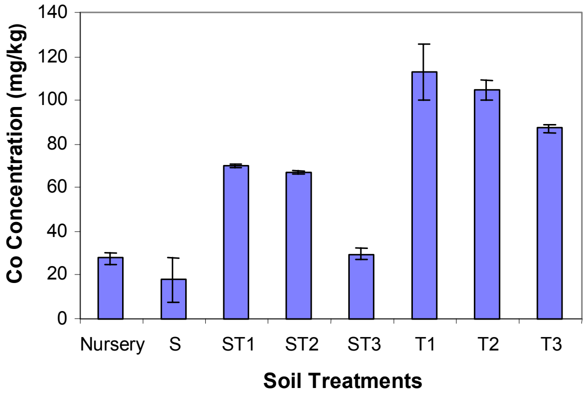
Figure 10: Copper, zinc and cobalt concentrations in *Atriplex stipitata* plants grown in seven soil treatments. Treatments: **1** = 100% sand dune soil. **2** = 25% (volume) sand dune soil, 75% (volume) tailing at natural tailing pH, mixed. **3** = 25% sand dune soil, 75% tailing with tailing pH 6-7, mixed. **4** = 25% sand dune soil, 75% tailing with a tailing pH 8-9, mixed. **5** = 12.5% sand dune, 37.5% tailing, at a natural tailing pH (3-4), overlying this is 50% sand dune soil. **6** = 12.5% sand dune, 37.5% tailing, at a tailing pH of 6-7, overlying this is 50% sand dune soil. **7** = 12.5% sand dune, 37.5% tailing, at a tailing pH of 8-9, overlying this is 50% sand dune soil.



(a)



(b)



(c)

Figure 11: Total soil concentration for Cu, Zn and Co, in the seven soil treatments. (a) Total Cu concentration in the seven soil treatments. (b) Total Zn concentration in the seven soil treatments. (c) Total Co concentration in the seven soil treatments. **S** = 100% volume sand dune. **ST1** = 25% volume sand dune, 75% volume tailing at pH 3-4. **ST2** = 25% sand dune, 75% tailing at pH 6-7. **ST3** = 25% sand dune, 75% tailing at pH 8-9. **T1** = 100% volume tailing at pH 3-4. **T2** = 100% tailing at pH 6-7. **T3** = 100 % tailing at pH 8-9.

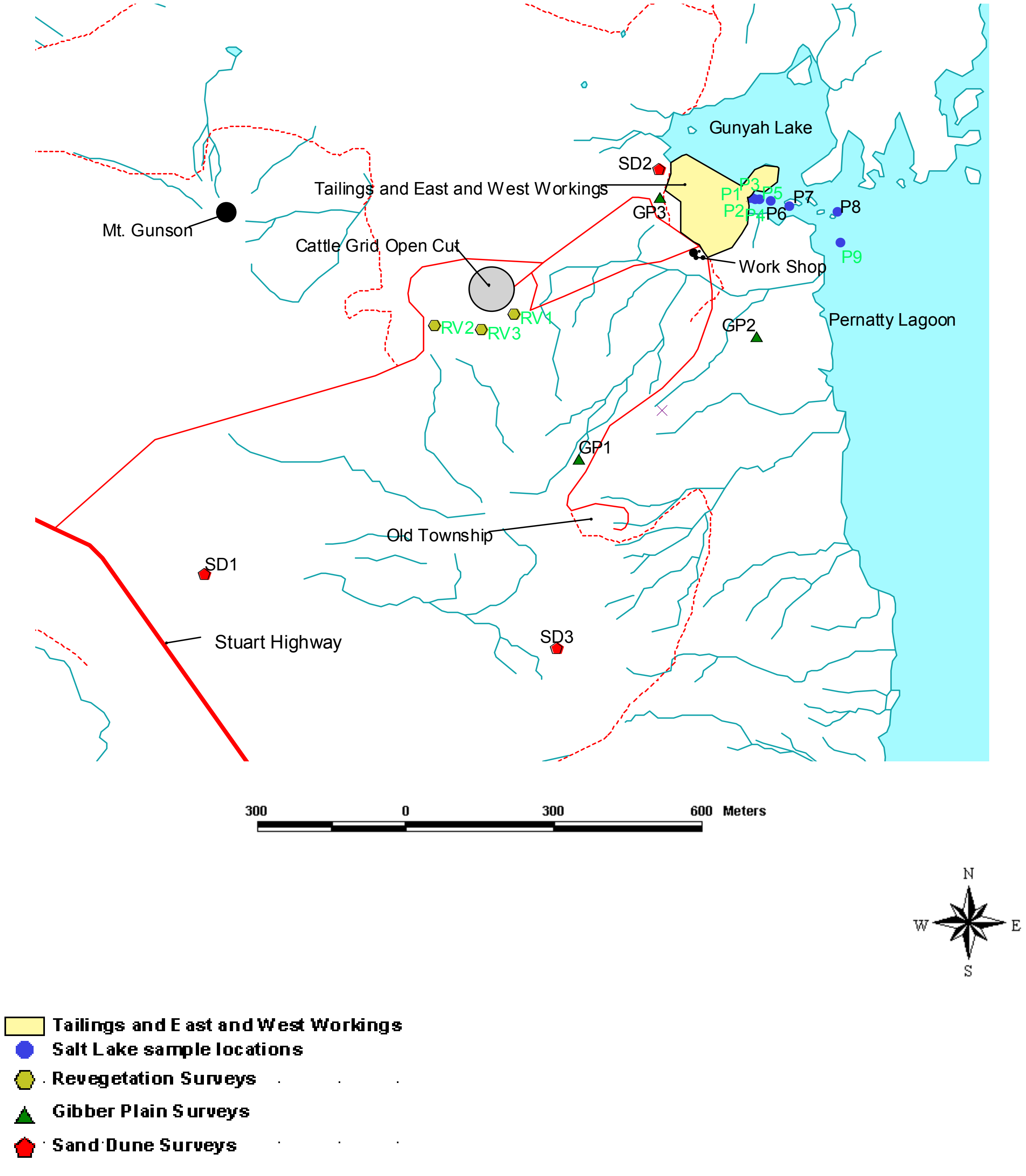
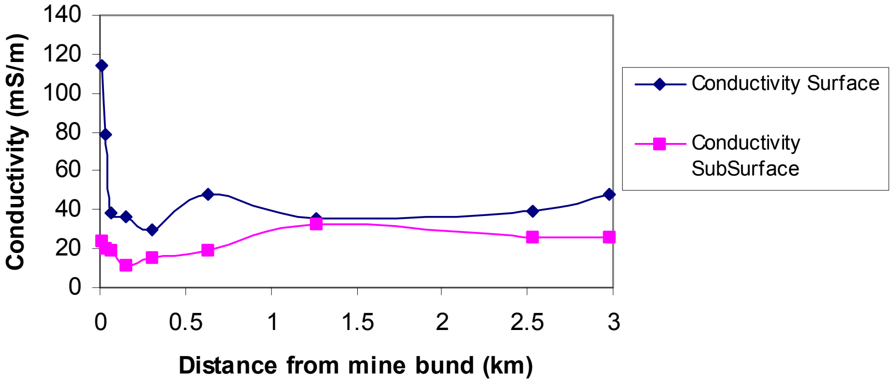
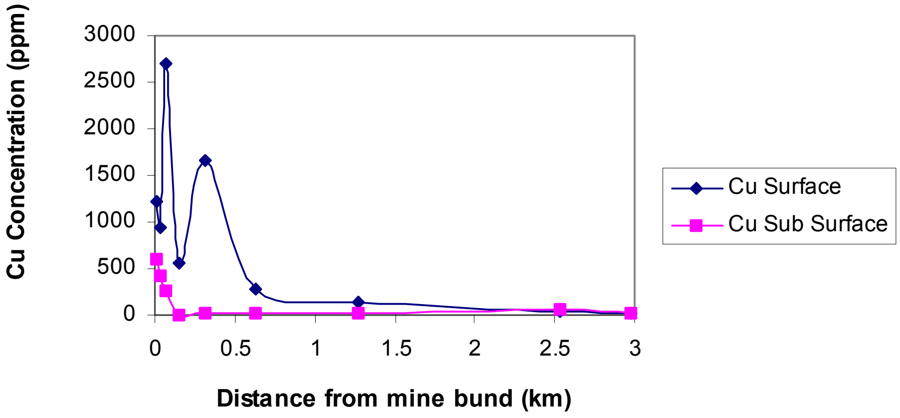


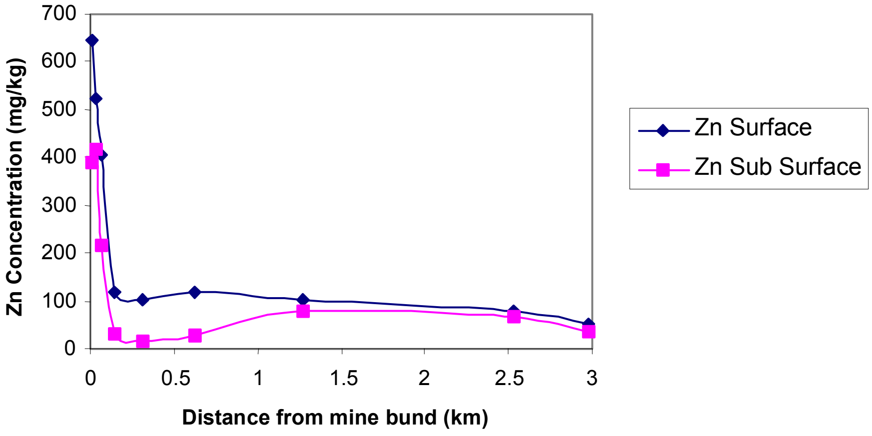
Figure 12: Mt Gunson Salt Lake and Vegetation survey locations. P = salt lake samples (P1-P9), RV = revegetation surveys (RV1-RV2), GB = gibber plain surveys (GB1-GB3), SD = sand dune surveys (SD1-SD3).


Conductivity (mS/m)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
Distance from mine bund (km)
Conductivity Surface
Conductivity SubSurface

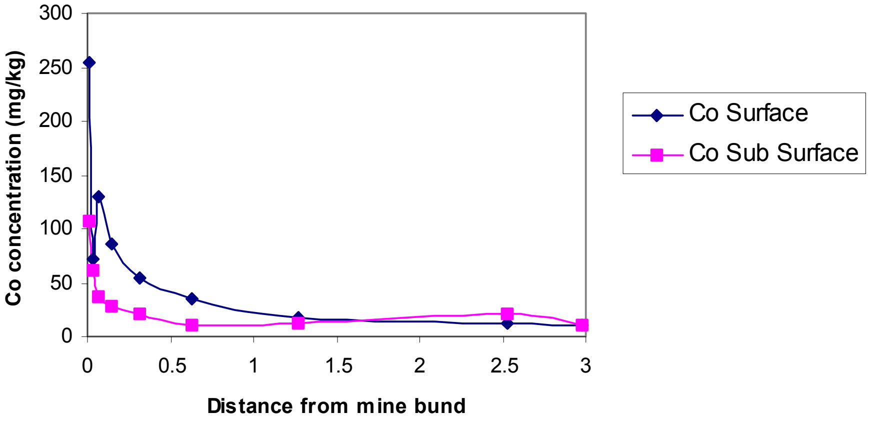
(a)


Cu Concentration (ppm)
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
Distance from mine bund (km)
Cu Surface
Cu Sub Surface

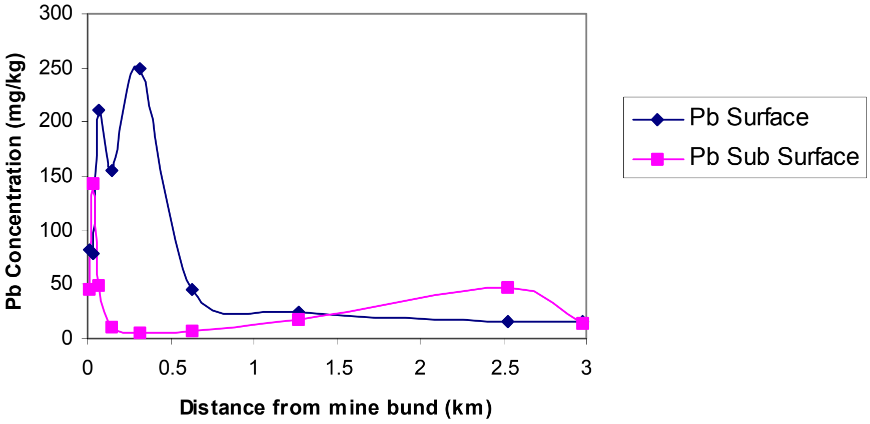
(b)


Zn Concentration (mg/kg)
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
Distance from mine bund (km)
Zn Surface
Zn Sub Surface

(c)



(d)

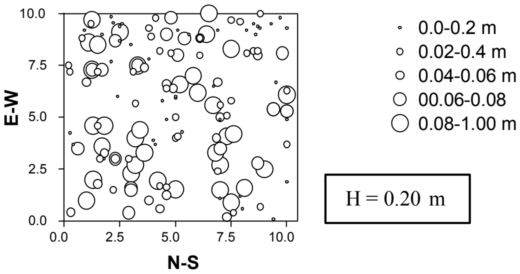


(e)

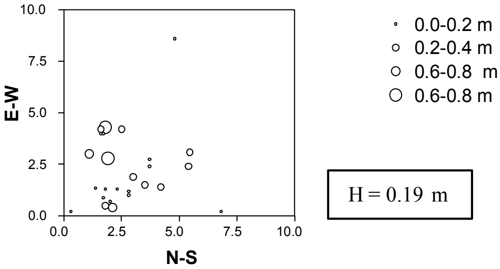
Figure 13: Surface (top 10cm), sub surface (bottom 10cm) of 1m deep cores along a transect from eastern bund out through Gunyah Lake into Pernatty Lagoon. (a) Surface and subsurface electrical conductivity readings vs distance from the eastern mine bund. Surface and subsurface copper (b), zinc (c), cobalt (d), lead (e) vs. distance from the eastern mine bund. All concentration results are graphed against distance in kilometres.

GP1

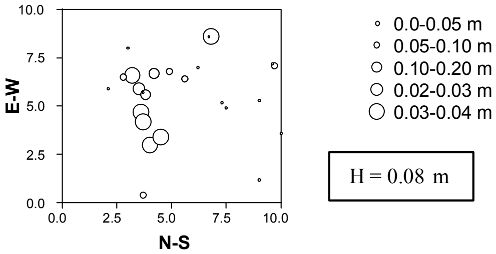
Atriplex vesicaria



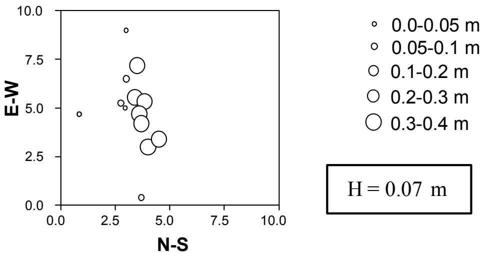
Atriplex stipitata



Sclerolaena brachyptera

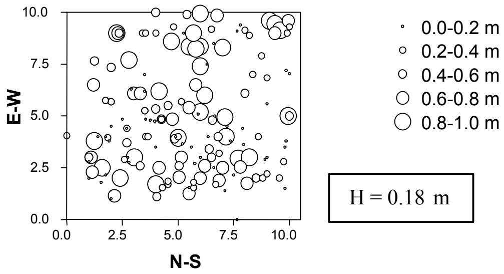


Sclerolaena eriacantha

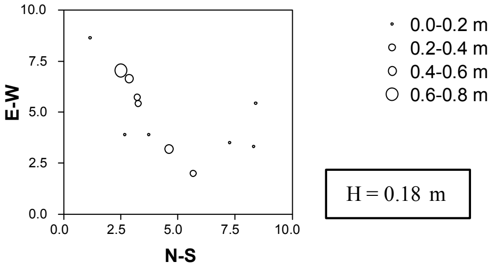


GP2

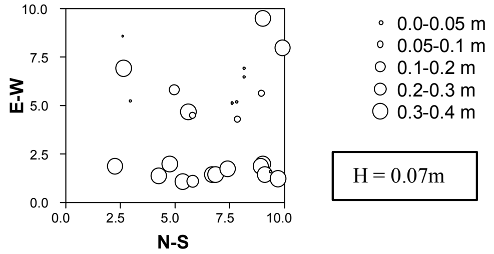
Atriplex vesicaria



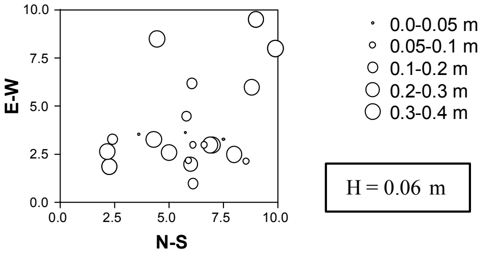
Atriplex stipitata



Sclerolaena brachyptera



Sclerolaena eriacantha



GP3

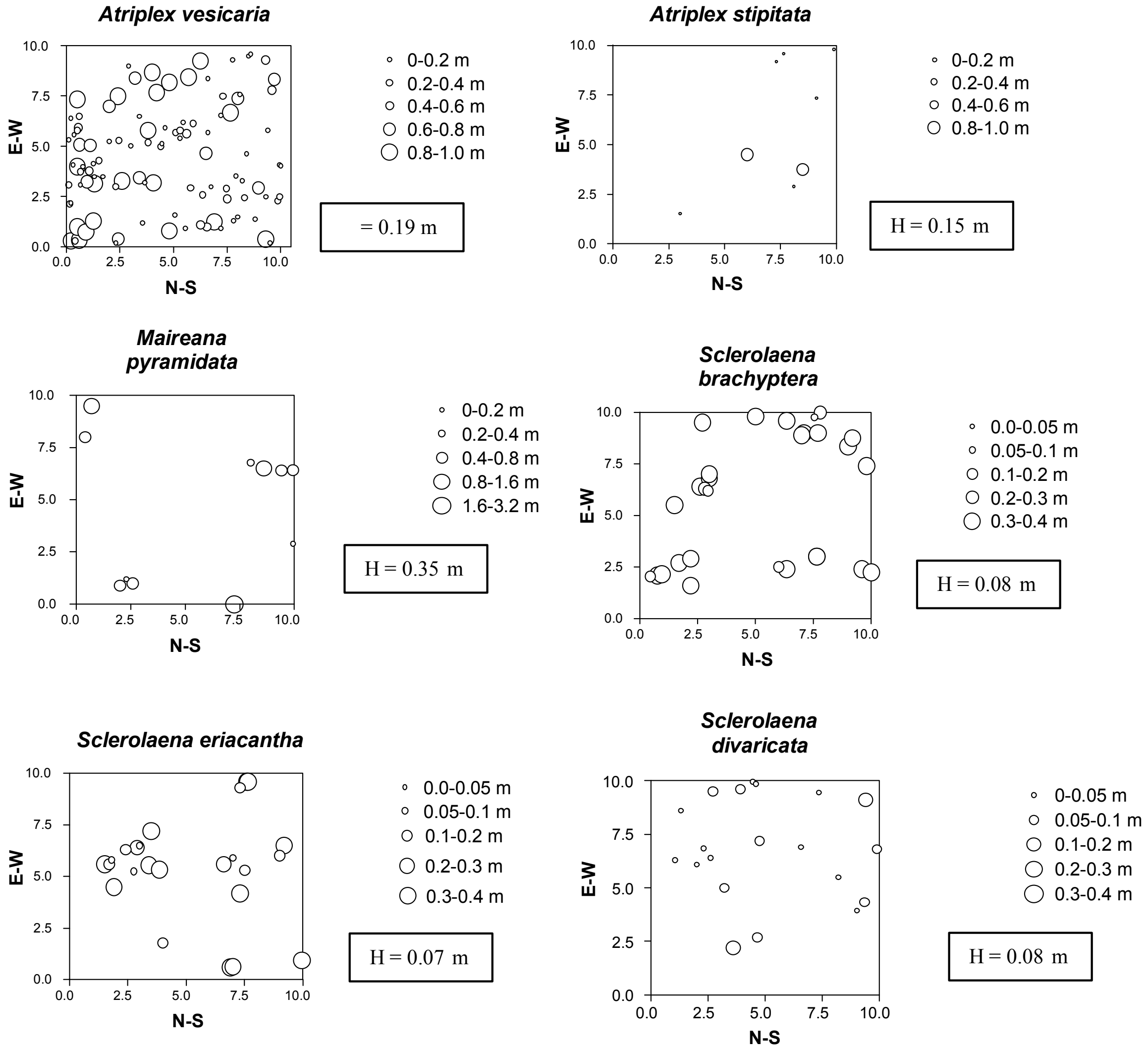
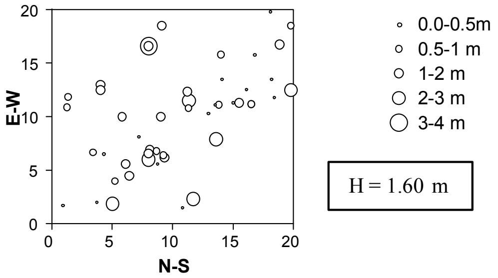
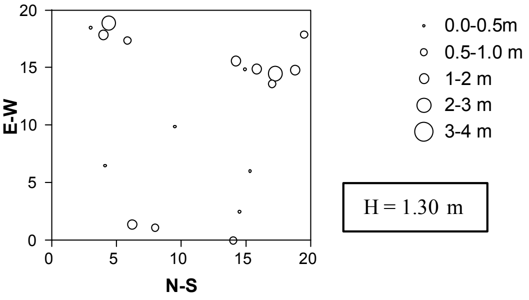


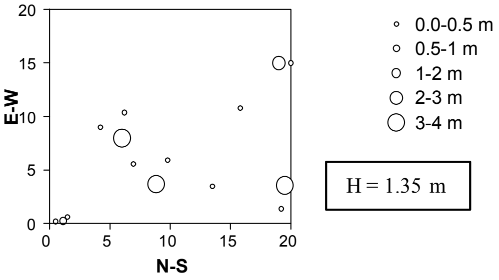
Figure 14: Distribution of dominant species that are found in quadrats surveyed on the three Gibber Plain quadrats. GP1 = Gibber Plain survey 1, GP2 = Gibber Plain survey 2, GP3 = Gibber Plain survey 3. Circles represent the NS, EW diameter of individual plants. H= average height of plants in quadrat.

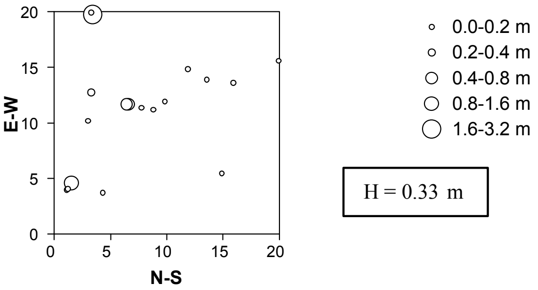
RV1

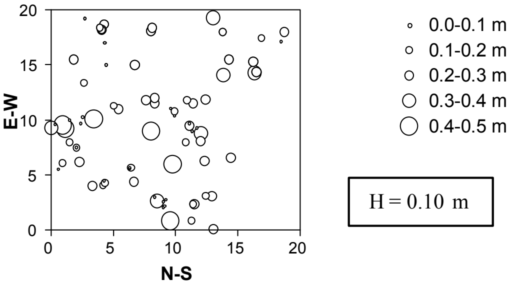

Dodonaea viscosa spp. angustissima

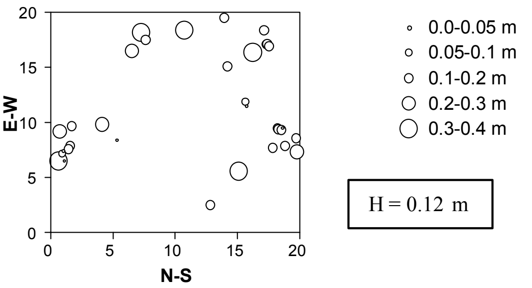

Acacia ligulata

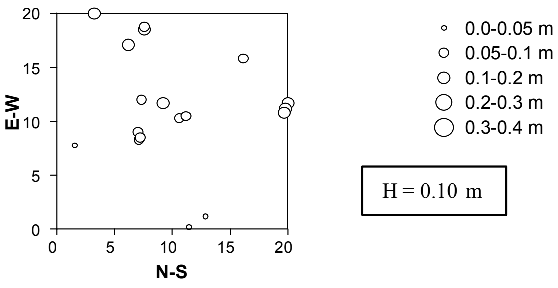
RV2

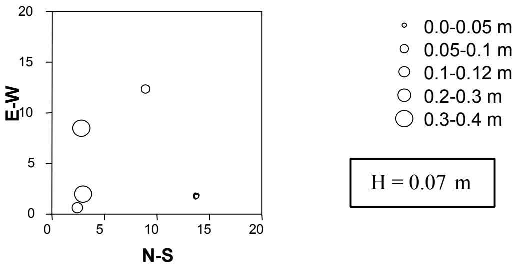

Dodonaea viscosa ssp. agustissima


Maireana pyramidata


Atriplex fissivalvis


Sclerolaena lanicuspis


Sclerolaena divaricata


Sclerolaena paradoxa

RV3

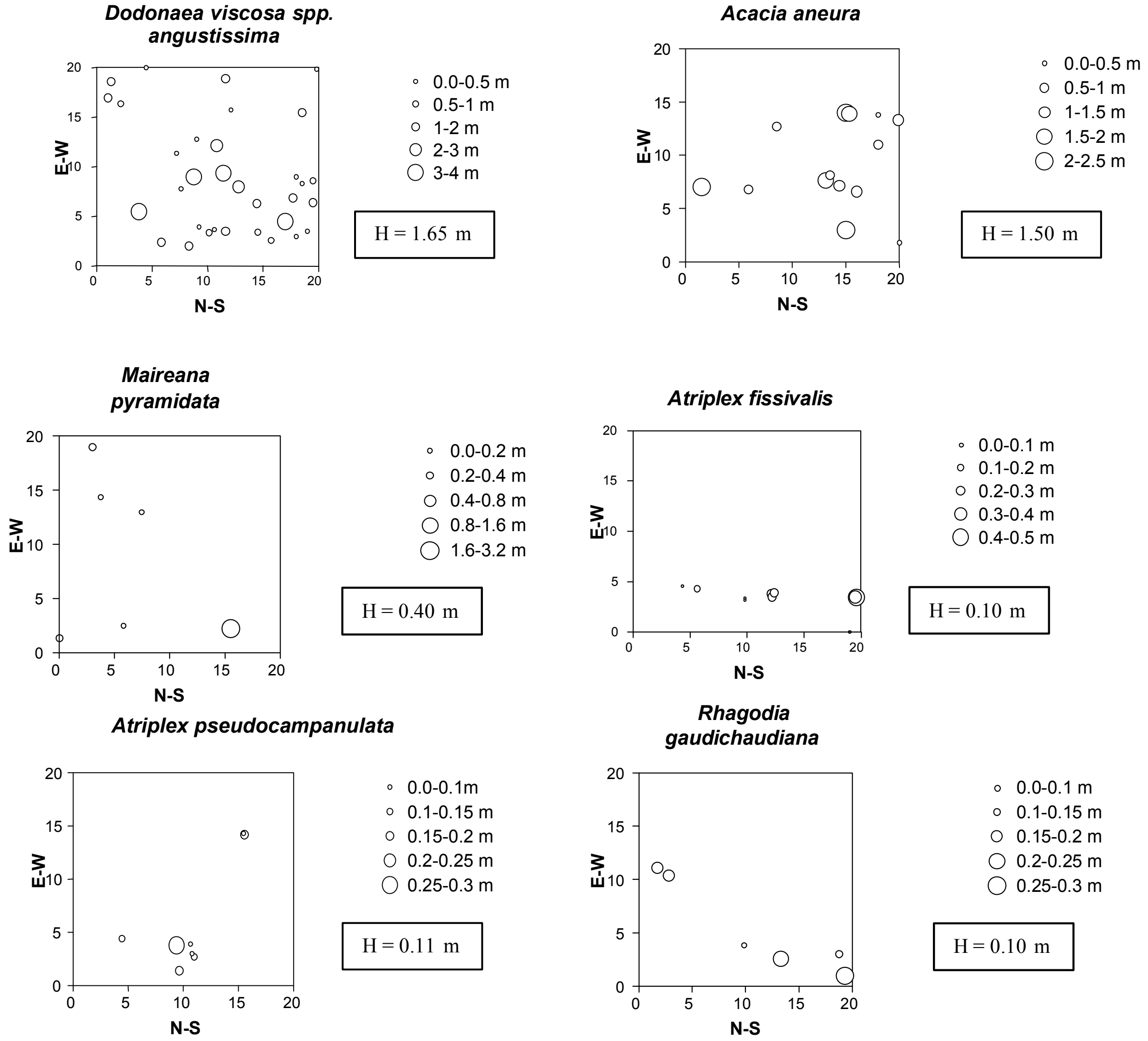


Figure 15: Distribution of dominant species that are found in quadrats surveyed on the three Revegetation sites. RV1 = Revegetation survey 1, RV2 = Revegetation survey 2, RV3 = Revegetation survey 3. Circles represent the NS, EW diameter of individual plants. H= average height of plants in quadrat.

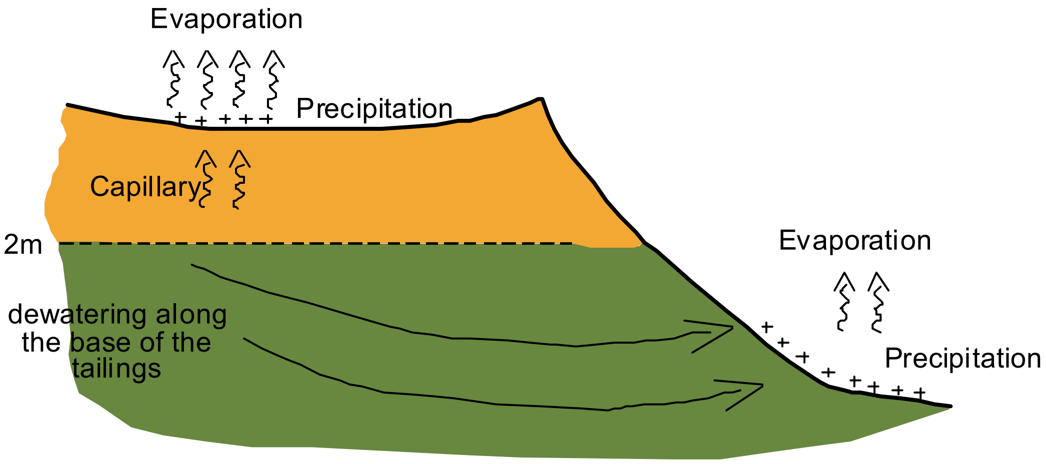


Figure 16: Schematic diagrams of evaporation dominated, metal distribution in the upper tailing. The dewatering of the tailing dam results in precipitation of minerals at the tailing base.

Figure 17: Tailing material from the old tailings seeping into Gunyah Lake (Aerial photo, PIRSA).

Table 1: Tailing Dam operational periods

Tailing	Period Operational
Old Tailings (East and West Lagoon workings).	1969-1971
Tailing 1	1974-1976
Tailing 2	1976- 1980
Tailing 3	1981-1986

Table 2: Soil treatments in the glasshouse pot experiments. Dried volume weights were used when potting material. M = mixed substrates, those in the left columns while NM = non mixed surface layer, seen in the right column.

Treatment	Tailing substrate (volume %, DW)	Sand Dune substrate (volume %, DW)	pH	Mixed (M) / Non Mixed (NM)	Sand Dune top surface layer (volume %)
1	-	100	8	-	-
2	75	25	3-4	M	-
3	75	25	6-7	M	-
4	75	25	8-9	M	-
5	37.5	12.5	3-4	M-NM	50
6	37.5	12.5	6-7	M-NM	50
7	37.5	12.5	8-9	M-NM	50

Table 3: Minerals present on the surface of tailing 1. Major Minerals **, Minor Mineral *.

SAMPLE	**Atacamite** $Cu_2Cl(OH)_3$	**Halite** $NaCl$	**Kaolinite** $Al_2Si_2O_5(OH)_4$	**Muscovite** $Kal_3Si_3O_{10}(OH)_2$	**Quartz** $Si0_2$
T1 1	*	*	**	*	**
2	*	*	*	*	**
3	*	*	*	*	**
4	*	*	*	*	**
5	*	*	**	*	**

Table 4 Average major elements concentrations from core 3.1, 3.2 and 3.3, on tailing three. All results in %.

	SiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	SO_3	LOI	Total %
T3.1	89.40	4.97	0.57	0.00	0.31	0.12	0.43	1.31	0.18	0.05	0.20	1.82	**99.37**
T3.2	89.87	4.26	0.61	0.00	0.22	0.06	0.27	1.07	0.17	0.05	0.17	1.68	**98.42**
T3.3	89.01	4.52	0.68	0.01	0.36	0.07	0.70	1.00	0.21	0.05	0.30	2.61	**99.51**

Table 5: Minerals present in the upper metre near T3.9. ** = Major minerals, * = Minor minerals.

	Atacamite $CuCl(OH)_3$	**Jarosite** $KFe_3(SO_4)_2(OH)_6$	**Kaolinite** $Al_2Si_2O_5(OH)_4$	**Muscovite** $KAl_3Si_3O_{10}(OH)_2$	**Quartz** $Si0_2$
Bulk sample	*	*	*	*	**

Table 6: Mineral composition of tailing base samples. Samples taken from increasing distances away from the base of tailing dam three.

		Atacamite	**Gypsum**	**Halite**	**Kaolinite**	**Muscovite**	**Quartz**
SAMPLE	Distance	$CuCl(OH)_3$	$CaCO_2$	NaCl	$Al_2Si_2O_5 (OH)_4$	$KAl_3Si_3O_{10} (OH)_2$	$Si0_2$
K1	0-3.5m	*	-	**	*	*	*
K2	3.5-8.3	*	**	*	*	*	**
K3	8.3-12.6	-	**	*	*	*	**
K4	12.6-15.7	-	*	**	*	*	*
S1	0-3.5m	*	**	**	*	*	**
S2	3.6-8.1	*	**	**	*	*	**
S3	8.1-11.3	**		**	*	*	**
S4	11.3-15.9	*	*	**	*	*	**
S5	15.9-18.9	**	-	**	*	*	**

Table 7: Cu, Zn, Co and Pb concentrations against landforms. All concentrations are in mg/kg. Standard deviation are given for each concentration reading. N = number of samples in each landform. A = Alluvial Sediment (anthropogenic), fa = alluvial fan, er = erosional rise, pd = depositional plain, aw = alluvial swamp.

N	Land form	Cu	Zn	Co	Pb
5	Afa	11708 ± 6394	2127 ± 985	1143 ± 251	222 ± 148
5	Aer	2734 ± 1670	831 ± 522	322 ± 121	142 ± 27
2	Apd	2275 ± 432	320 ± 56	456 ± 197	62 ± 8
3	Aaw	14156 ± 7899	845 ± 311	915 ± 526	265 ± 150

Table 8: Average plant health, for the three tailing plot species. 1= healthy condition, 2 = good condition, 3 = poor condition, 4= dead (n=3).

	Nursery	**Sand Dune**	**Sand Dune/Tailing**	**Tailing**
A. vesicaria	1	1	3	4
S. artemisioides ssp. coriacea	1	2	4	4
D. viscosa ssp. angustissima	1	3	4	4

Table 9: Plant up take forms, average soil / plant concentration and toxic concentration of metals analysed by ICPAES. Deficiencies in plants for Cu is between 2-5 mg/kg, Zn 10-20 mg/kg and Co is at less than 0.02 mg/kg. (Berkman 1995; Marschner 1997; Kabata-Pendias 2001). Average tolerance of salinity is <0.49 dS/m, with tolerable pH ranges for plants at 5.5-8.5 units (Rengasamy and Bourne, 1997).

Element	Forms taken up by plants	Average soil concentration (mg/kg)	Average plant concentration (mg/kg)	Average excessive or toxic concentrations in plants (mg/kg)
Copper (Cu)	Cu^+,Cu^{2+}	2-100	1-20	>20
Zinc (Zn)	Zn^{2+}, $Zn(OH)_2$	10-300	1-100	>400
Cobalt (Co)	Co^{2+}	1-40	8-100	>100

Table 10: Seed germination experiments in the glasshouse of eight species in four different soil substrate treatments. AV = *Atriplex vesicaria,* AS = *Atriplex stipitata,* AL = *Acacia ligulata,* SA = *Senna. artemisioides ssp. coriacea,* DA = *Dodonaea. viscosa ssp. angustissima,* MS = *Maireana sedifolia,* MP = *Maireana pyramidata,* ET = *Enchylaena tomentosa.* Treatment 1 = sand dune soil. Treatment 2 = tailing substrate at pH 4.5 (natural). Treatment 3 = tailing substrate at pH 6.5. Treatment 4, tailing substrate at pH 8. S = stratified seeds (n=8). NS = none stratified seeds (n=8).

	Treatment 1		**Treatment 2**		**Treatment 3**		**Treatment 4**	
	S	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**
AV	4	3	0	0	0	0	0	0
AS	8	7	0	0	0	0	0	0
AL	2	2	0	0	0	0	0	0
SA	4	3	0	0	0	0	0	0
DA	6	4	0	0	0	0	0	0
MS	0	0	0	0	0	0	0	0
MP	0	0	0	0	0	0	0	0
ET	8	8	0	0	0	0	0	0

Table 11: Total and Available copper, zinc and cobalt in different soil substrates, with ± standard deviation.

Soil/Substrate Type	**State**	**Cu (mg/kg)**	**Zn (mg/kg)**	**Co (mg/kg)**
Nursery Soil	*Total*	**98 ± 3**	**134.5 ± 0.5**	**28 ± 3**
	Available	***<0.2***	***0.185* ± 0.01**	***<0.2***
Sand Dune	*Total*	**194 ± 56**	**35 ± 7**	**8 ± 3**
	Available	***<0.2***	***<0.09***	***<0.2***
Tailing pH 3-4	*Total*	**1975 ± 25**	**870 ± 10**	**113 ± 13**
	Available	***1695* ± 45**	***840* ± 10**	***107* ± 3**
Tailing pH 6-7	*Total*	**1780 ± 80**	**815 ± 15**	**104 ± 4**
	Available	***14* ± 0.05**	***320* ± 10**	***17* ± 0.17**
Tailing pH 8-9	*Total*	**1560 ± 10**	**860 ± 20**	**87 ± 2**
	Available	***0.2*± 5^{-04}**	***24* ± 1.6**	***6.2* ± 0.2**
Tailing/Sand Dune pH 3-4	*Total*	**1255 ± 105**	**560 ± 10**	**67 ± 2**
	Available	***75* ± 11**	***560* ± 20**	***50* ± 1**
Tailing/Sand Dune pH 6-7	**Total**	**1175 ± 65**	**540 ± 10**	**69 ± 3.7**
	Available	***3.6* ± 0.1**	***87.5* ± 0.14**	***8.5* ± 0.2**
Tailing/Sand Dune pH 8-9	**Total**	**515 ± 5**	**220 ± 10**	**29.5 ± 2.5**
	Available	***0.25* ± 0.05**	***12.5* ± 0.2**	***3.18* ± 0.04**

Table 12: List of species sustained in different vegetation communities. Species are divided into three subgroups: Trees, Shrubs and Ground Covers. Plant common names are in brackets. * = species not usually found in this plant community but local environmental factors assist in plants being present. Plant names underlined were not present in the vegetation surveys, but have been identified in the past.

Community	**Trees**	**Shrubs**	**Ground Covers**
Gibber Plains	_Eremophila tree spp._	_Atriplex vesicaria_ _Atriplex stipitata_ _Atriplex spongiosa (Pop Saltbush)_ _Maireana sedifolia_ _Maireana pyramidata_ _Maireana astrotricha (Low Bluebush)_ _Arthrocnemum ssp. (Samphire)_ _Disphyma spp. (Pigface)_	_Sclerolaena brachyptera (Short-Winged Cooperburr)_ _Sclerolaena divaricata (Pale Poverty-Bush)_ _Sclerolaena eriacantha (Silky Copperburr)_ _Sclerolaena paradoxa (Cannon-Ball)_ _Emex australis (Spiny Emex)_ _Xanthium_
Revegetation Sites	_Dodonaea viscosa ssp. angustissima_ _Acacia ligulata_ _Acacia aneura (Sand Mulga)_ _Senna phyllodinea (Woody Cassia)_ _Senna artemisioides ssp. coriacea_	_Atriplex fissivalvis (Gibber Saltbush)_ _Atriplex pseudo campanulata (Mealy Saltbush)_ _Atriplex acutibractea_ _Maireana triptera (Three Winged Bluebush)_ _Maireana eriantha (Woolly Bluebush)_ _Maireana pyramidata_ _Solanum petrophilum (Rock Nightshade)_	_Rhagodia gaudichaudiana (Cottony Saltbush)_ _Sclerolaena divaricata_ _Sclerolaena lanicuspis (Woolly Copperburr)_ _Sclerolaena paradoxa_
Sand Dune	_Acacia papyrocarpa (Western Myall)_ _Acacia aneura_ _Acacia ligulata_ _Dodonaea viscosa ssp. angustissima_ _Callitris columellaris (White Cypress Pine)_ _Callitris preissii_ _Callitris glauca (Cypress Pine)_	_Enchylaena tomentosa (Ruby Saltbush)_ _Alectryon oleifolia_ _Atriplex fissivalvis_ _Atriplex pseudo campanulata_* _Arthrocnemum spp._* _Maireana pyramidata_ _Maireana sedifolia_	_Xanthium spp._ _Sclerolaena divaricata_ _Brassica tournfortii (Wild Turnip)_

References

Allan R (1997) Introduction: Mining and metals in the environment, J. Geochem. Explor. 58: 95-100.

Anon (1988) Adelaide Geochemical Co., Mt Gunson. Miner Ind Q South Aust 40: 15.

Berkman DA (1995) Field Geologists' Manual, Australian Institute of Mining and Metallurgy, Australia.

B.O.M [Bureau of Meteorology] (Oakden Hill data, S.A.) www.bom.gov.au

Borden R (2001) Geochemical evolution of sulphide–bearing rock soils at the Bingham Canyon Mine, Utah, Geochem. Explor. Environ. Analy. 1: 15-22.

Campbell MA (1996). Biology. Bunjamin/Cummings Publishing Company Inc. California, U.S.A.

Corkin B (1984) Mt Gunson: Memories of a mining community.

Cunningham GM (1992) Plants of Western New South Wales, Inkata Press, Australia.

Greger M (1999) Metal availability and bio-concentration in plants, in Heavy Metal Stress in Plants, Springer, Heidelberg.

Houba VJG, Temminghoff EJM, Gaikhorst GA, Van-Vark W (2000) Soil analysis procedures using 0.01 M calcium chloride as extraction reagent, Comm. Soil Science Plant Analy. 31: (9-10) 1299-1396.

Houston ML (1977) Mining operations at the Cattle Grid copper deposit – Mount Gunson, Miner Resour. Rev. South Aust 141: 64–68.

Jessop JP, Toelken HR (1986) Flora of South Australia, 4th ed. South Australian Government Printing Division, Adelaide.

Kabata-Pendias A, Pendias H (1991) Trace elements in soils and plants 2nd edition. CRC Press. U.S.A.

Kabata-Pendias A (2001) Trace Elements in Soils and Plants 3rd edition. CRC Press. U.S.A.

Langkamp P (1987) Germination of Australian native plant seeds, Inkata Press Australia

Lintern MJ, Sheard MJ, Gray DJ (1998) Geochemical studies of the regolith at the Mt Gunson copper deposits, Stuart Shelf, South Australia. In: CRC LEME report 76R.

Ljungberg J, Ohlander B (2001) The geochemical dynamics of oxidising mine tailings at Laver, north Sweden, J. Geochem. Explor. 74: 57-72.

Markos G, Bush KJ (1982) Geochemical processes in uranium mill tailings and their relationship to contamination. In: Management of wastes from uranium mining and milling, Int. At. Energy Agency Austria.

Marschner H (1997) Mineral Nutrition of Higher Plants Second Edition, Academic Press Limited. London and U.S.A.

McLaughlin M J, Hamon RF, McLaren, RG, Speir, TW, Rogers SL (2000). Review: A bioavailability-based rationale for controlling metal and metalloid contamination of agricultural land in Australia and New Zealand, Aust. J. Soil Res. 38:1037-86.

Morrell JW, Stewart BR, Gregg HEP, Bolan NS, Horne D (1996) An assessment of Sulphide Oxidation in abandoned base-metal tailings, Te Aroha, New Zealand, Environ. Pollut. 94:217-225

Mt Gunson, operations manual (Vol. 1-3) 1974 – 1984.

Osborne JM (2000) Tailing revegetation – on non-ameliorated substrate, Inter Journ Surf Min, Reclam Environ 14: 161-169

Pain C, Chan R, Craig M, Gibson D, Ursem P, Wilford J (2000) RTMAP Regolith Database filed and users guide, 2nd Edition, CRC LEME Report 138

Peverill KI, Sparrow LA, Reuter DJ (1999) Soil Analysis: an Interpretation Manual, CSIRO Publishing, Melbourne, Australia

Preiss WV (1987) The Adelaide Geosyncline: Late Proterozic stratigraphy, sedimentation, palaeontology and tectonics, Geol.Surv. South Aust Bull 53: 384 – 389.

Puccini O (1996) Assessment of Remedial Operations Mt Gunson Tailings Facility.
pp 1–18 (PIRSA internal report).

Rattigan JH (1988) The Cattle Grid deposit. In: Geological Aspects of the Discovery of Some Important Mineral Deposits in Australia. Monograph Series 17. pp 121 – 124.

Rengasamy P, Bourne J (1997) Managing sodic, acidic and saline soils, Cooperative Research Centre for Soil & Land Management, Australia.

Ritcey GM (1989) Mobility – Migration and Salt Formation by capillary Action.
In: Tailings management problems and solutions in the mining industry.
Elsevier 1989. Pages 329 – 349.

Simpson SL, Apte SC, Hortle KG, Richards DG (1998) An evaluation of Copper Remobilisation from mine tailings in sulfidic environments, Jour Geochem Explor 63:203-215.

Tonkin DG, Creelman RA (1990). Mount Gunson copper deposits. In Geology of Mineral Deposits of Australia and Papua New Guinea (Ed. F.E. Hughes), The Australasian Institute of Mining and Metallurgy: Melbourne pp 1037 – 1043.

Warren TJ, Hammond RP (1984) Rehabilitation at Mount Gunson. Johnny Green’s Journal 4: 3.

Williams DJ (1995) Natural versus constructed rehabilitation of open pit mine sites world wide, AMEEF occasional paper 8, Australia.

Williams PA (1990) Oxide Zone Geochemistry. Ellis Horwood England.

Wilson (1996) Acid deposition and heavy metal mobilisation, Appl. Geochem. 11: 133-137.

Appendix

APPENDIX I

Mine history prior to 1974

F. Young, discovered the Mount Gunson copper deposit in 1875, by identifying outcropping oxidized copper around where the Main Open Cut eventually was worked. Shortly after sulphide copper was discovered, and mined on the southern side of Gunyah Lake (original West Lagoon workings, 1895). Small parcels of high grade ore were mined over a 10 year period. In 1911 the Mount Gunson Company was formed. A leaching plant was built at the site in 1915 but proved unsuccessful. The company concluded operations in 1919. Zinc Corporation Limited (1937 – 1943) mined 32 380 tonnes of ore with an average grade of 3.5% copper, until a minimum grade of 2.5% could no longer be maintained. This was conducted approximately 2 km south of the original lagoon workings, at the Main Open Cut. Between 1964 – 1965 Jurvois Sulphates, were unsuccessful in producing copper sulphate by leaching the ore. Austmix Pty. Ltd. between the years of 1966 – 1968, conducted extensive exploration in the Mt. Gunson region and identified a reserve potential of three million tonnes of greater than one percent copper ore. They had discovered the East Lagoon deposit and the full extent of the historic West lagoon deposit, but conducted no mining. Between 1969 to 1971, mining of the East and West Lagoon deposits occurred. Approximately 234 000 tonnes of sulphide ore were mined, with a grade of 0.79%, producing 1850 tonnes of copper and

2800kg of silver (small tailings produced). The operations finally ceased due to poor ore grade, infrastructure and spiralling downturn in copper prices (Tonkin & Creelman).

Gunyah Lake Breach

The eastern bund wall where the salt lake transect started, was due to copper precipitated salt crystals being found on the Gunyah Lake side of the wall. No structural breach in the bund wall exists. On the tailing side of the wall, tailing material has become a fine grained brown clay, textured material. The surface is not stable and evidence exists of Kangaroos getting bogged. This material is seeping through the bund wall and precipitating on the Gunyah Lake side.

Dimple revegetation strategy

Since mining commenced at Cattle Grid in 1974-1986, the revegetation of affected land had taken place. The reconstruction of the natural stratigraphy of the area was undertaken to ensure the success of revegetation, by ensuring barren sandstone was below the reach of the plant roots. Sandy overburden at the site was leveled off and a similar topography of the surrounding area was constructed. Above this 1-3m of sandy surface and clay sub surface material was dumped on the site and levelled off. Then surface sand dune soil was dumped into piles between 0.5-1.5m high. This has become known as the 'Dimple Dumping'. 'Dimple Dumping' reduced wind speeds and encouraged wind blown seeds deposition. Care was taken so that no level corridors were created between the piles. This created microclimates for greater natural plant establishment, whilst at the same time preventing loss of sand dune soil from rain run offs, thus preventing erosion. Initially the construction of EW trending dunes failed to encourage natural regeneration due to high wind velocity, erosion and lack of microclimates for plant establishment. This then resulted in the 'Dimple Dumping' method being developed. The majority of the 'Dimples' had been worn away where the vegetation had been established. Where areas of vegetation establishment had been poor, loss of topsoil by wind and rain have occurred, and 'Dimples' may remain dominant features. This is seen predominantly in a small area of the revegetated site, SW of the Cattle Grid mine. Within the same area erosion has resulted in the complete loss of surface sand dune material and has left a barren surface exposed (Mt Gunson 1974 – 1986).

XRD Preparation and Machine Specifications

Sample preparation

100 g of each of the tailing samples were dried in a watch glass. Once dried the sample was then milled in a tungsten carbide crucible and ring grinder. The crushed fine powder was divided into two and analysis for major and trace elements.

- <u>Major elements</u>: small amounts of powdered sample put in crucible and ignited at 960° C, to identify loss of ignition (LOI). One gram to 4grams of flux was mixed and then the sample was fused using high temperatures from a propane oxygen flame. Discs produced, resulted in major analysis of elements such as SiO_2, Al_3O_3, MnO, and Na_2O. The machine specifications are: Philips PW 1480 XRF Spectrometer.

- Trace elements: Resulted in approximately 5 - 10 g of powdered samples being mixed with ~1 ml of binder solution (Poly Vinyl Alcohol) and pressed to form pellets. The samples were analysed using a Philips PW 1480 XRF Spectrometer.

EC and PH

Conductivity was recorded for each sample collected by using a Hanna Hi 8733 conductivity metre in the laboratory. Electrical Condictivity (EC) and pH in 1:5 (sample 5g: RO [reverse osmosis] water, 25 ml) ratio was tested and. pH of each sample was recorded, using the Activon pH/mV meter. pH readings were taken from the 1:5 conductivity solution. The 1:5 ratio solution was put in a rotator for 1 hour, before readings were taken. Temperature of each water sample was recorded before being analysed so that conductivity readings could be compared to a standard to give accurate electrical conductivity (EC) readings.

ICP Procedure

Five grams of plant sample to 7ml of HNO_3 with 50 ml of RO water making the extractant solution. A 1:10 plant:acid/water ratio was formed to determine element concentrations within the shoots of the plants and total element concentrations in the soil. Soil analysis required only 0.01 g.

Logs of Tailing Cores

Fine sand 125-250μm, Medium sand = ~400-500μm, Coarse sand 500-100μm,
Very coarse 1000-2000μm.

T1.1

0-30cm	Top 5cm a dry white course grained, green sandy composition. Rest of the section is a course grained orange red sand.
30-60	Is a pink course grained sand. Throughout this section is fine grained clay like orange streaks.
60-100	This section is composed of a yellow fine grained clay. White, pink and orange streaks are evident in this section of the core. The clay is very stick in texture and becomes very yellow near the 1m mark.

T1.2

0-16cm	Surface material is a sandy green to white coloured material. It is course grained. Below this surface is a light yellow to orange medium grained material.
16-66	The top 30 cm of this section of the core is dominated by yellow to orange core which gradually changes colour to a pink medium grained, than back to the yellow orange colour with flecks of the above pink material.
66-80	This unit is predominantly course grained sandy material or intermixed colours of yellow, orange, pink and grey.
80-100	A yellow fine grained clay like material dominants in this unit. The clay is very sticky.

T2.1

0-2cm	Course grained, green to white in colour.
2-36	This unit is a course grained sandy unit which changes in colour from yellow to white to yellow to orange. Each section is about the same size in the unit.
36-70	The unit has variable colour and grain size. The top 8cm is dominated by a course grained sand, this is followed by a 5cm orange medium grained sand. The next section is dominated by a 5cm pink clay. This is followed by a medium grained orange unit which ends with a 6cm sandy dry red unit.
70-100	Clay is the dominant unit. The top of this section of the core is dominated by a 6cm grey sticky clay. Then a 5cm yellow/orange clay unit exists. The rest

of the unit is a grey clay that is very wet and sticky. The bottom 4cm of this core turns into an orange medium grain sand.

T2.2

0-10cm Light course grained green surface, which changes into a yellow course grained material.

10-47 This is a course grained unit that start with the above light yellow sand material to an orange sand.

47-89 Homogeneous yellow course grained sand.

89-100 The top of this unit is a dark yellow coloured coursed grained sand that is about 9cm deep. A 2cm course, dark green layer exists below the yellow unit. The remained or the core is a pale orange course grained unit.

T2.3

0-2cm Dark green course grained material.

2-12 Light green course grained material.

12-57 Pale yellow sand that is homogeneous throughout the unit.

57-100 The first 20cm of this unit is interlayered with yellow, orange and white course grained sand. The rest of the unit is a course grained orange sand, with a dark orange lense between 80-85cm.

T2.4

0-11cm Dark green course grained surface layer.

11-30 A course grained green sand material in the top 3 cm, followed by a pink medium grained sand.

30-80 Yellow course grained sand. Between 65-73cm the unit becomes a fined grained clay. The rest of this unit is the yellow course sand.

80-100 This unit has variable grain sizes. This unit is a pale yellow material that is course grained to fine grained. This grain size difference is random throughout this section of the core.

T3.4

0-5cm	Light green surface layer that is a course grained material
5-40	Light yellow at the top of the unit to orange at the bottom of the unit. The unit is homogeneously course grained.
40-60	This unit is a light yellow course grained sand unit.
60-80	The unit goes from a yellow to orange in colour. This unit has two distinct red patches between 60-70cm. These patches are mainly medium grained.
80-100	This unit is exactly like the red patches above, but becoming more fine grained further down the unit to a red clay unit.

T3.5

0-10cm	This core was taken in a dried out drainage pond in the centre of the tailing. The top 10cm is a fine grained clay material that yellow in colour, and sticky.
10-20	A fine grained, sticky yellow to pink clay unit.
20-70	This unit is dominated by red medium grained sand material, with some yellow clay material in the upper 10cm of the unit.
70-100	The unit is a grey course sand with little lenses of red grained sand throughout the unit.

T3.6

0-35cm	The top 3cm is a light green course grained sand. The rest of the unit is orange to pink (near the bottom), which is a course to medium grained sand.
35-50	This unit is yellow in colour and course grained.
50-85	The first 17cm of this unit is a dark orange medium grained sand, that is followed by a light orange/yellow course grained section. The bottom 4 cm is comprised of a white course grained sand.
85-100	This unit is characterised by having an upper comprising of light red/pink to dark red course grained sand. At the 92-95cm depth a green medium grained strip of sand is found. This is followed by the dark red course grained sand.

T3.7

0-2cm	Yellow surface of tailing, as in drainage pond on tailing. Green fine grained nodules have formed on the surface of the tailing.
2-25	Pink to red medium grained sand. This section of the core shows some of the material becoming clay like, very fine grained.
25-40	This unit is an orange/pink medium grained sand that changes into a grey/pink medium grained sand unit.
40-70	The top 23cm of this unit is medium grey sand, that changes into a fine grained grey clay that is sticky.
70-100	This unit is a fine/medium grained orange/grey sand that turns into a medium grained grey sand at about 85cm.

T3.8

0-10cm	The top 2cm of this unit is a green to yellow course grained sand. The next 7cm of the unit is a yellow course grained sand. The bottom of this unit is a white course grained sand.
10-35	Top of this unit is yellow with patches of white sand that are both course grained. The bottom two thirds is comprised of orange course grained sand.
35-56	The top 15 cm of this unit is made up of pink course grained sand. That mixes with orange course grained sand in the lower section of this unit.
56-100	This unit is made up to pink sand that is very course. At the 85cm mark the pink sand becomes lighter, to become a whitish pink course grained sand.

T3.9

0-10cm Is a green sand course grained material that changes to a yellowy green at about 4cm.

10-44 A green/yellow course top to a whitish yellow course grained sand at the bottom of the unit.

44-70 The top 10cm is a green/yellow course grain sand that then changes into interlayers of orange and white course grained sand, each being ~5cm thick.

70-100 This unit has a yellow upper layer of about 10cm, followed by a pink sand layer and finally a yellow layer of 10cm. All are course grained sand material.

Log Cores of Gunyah Lake and Pernatty Lagoon Sampling.

Fine sand 125-250µm, Medium sand = ~400-500µm, Coarse sand 500-100µm,
Very coarse 1000-2000µm.

Core 1:

The core penetrated 30cm into the upper surface of the lagoon. The top 6cm was a very course grained dark brown sand, with several halite cubes evident. The next 4cm was a very fine grained clay unit the same colour as above. The rest of the core was like the upper 6cm, but slightly drier.

P1A Top 10cm, Hue 7.5yr4/4, Hue 7.5yr8/3 (wet, dry). With the grain size being course sand and clay

P1B Bottom 10cm, Hue 5yr5/4, Hue 7.5yr8/2. The grain size of this sample was medium to course sand.

Core 2:

The core sample is 30cm. The top 15cm is a fine grained orange clay, with green flecks throughout. In this section of the core are about 30 cubic salt crystals (halite) ranging from $0.5cm^3$ to $1cm^3$. The next 10cm is dominated by a sandy medium to course grained brown sand. The bottom 5 cm of the core becomes medium to course grained red clay.

P2A Top 10cm of sample, Hue 7.5yr5/8, Hue 7.5yr8/3, that is classified as a fine sand to clay.

P2B Sample is 10-20cm from the core, Hue7.5yr5/6, Hue7.5yr8/2, a medium course grained sand.

P2C The bottom 10cm of core, Hue7.5yr4/6, Hue7.5yr7/3, that is a medium to course sand.

Core 3:

This core sample is 35cm deep. The top 11cm of the core is a brown sandy unit. This is followed by a brown to orange clay unit that has several cubic halite samples present. This unit is from 11-15cm. The unit below this that extends to 18cm is a course sand unit that is light brown. From 18-22cm we have a soil unit with a 1cm brown A horizon followed by a 2cm layer of interlayers (9 packages of 2mm) of red (clay) and brown soil that finally ends with a 1cm brown layer. All layers are fine grained. The remainder of the core is a sticky brown clay, that darkens gradually down the core.

P3A Is the top 10cm of the core, Hue 5yr5/4, Hue10yr 7/4, medium grained sand.

P3B This sample is from 11-15cm, Hue 7.5yr6/6, Hue 10yr8/3, a fine sand to clay.

P3C From 15-18cm, Hue 7.5yr5/6, Hue7.5yr 8/2, medium grained sand.

P3D This sample is from 18-22cm, with the red clay having a wet colour of Hue 10R4/8, and the brown horizons having a wet colour of Hue 10R4/3. The combined dry colour is Hue 7.5yr7/2, a fine grained soil.

P3E This sample is from the bottom 10cm of the core, Hue 7.5yr7/3, course grained sand.

Core 4:

This core is 43cm deep. The top 2mm is a sandy grey brown sand this salt crystals evident. The top 10cm of the core is a fine grained clay that is grey to green in colour. At the 15cm mark is a 0.5cm black layer, that is fine grained and has a wet colour code of Hue 7.5yr1/1. The remained of the core is a course grained red sand that lightens down the core.

P4A The top 10cm of the core, Hue 7.5yr5/4, Hue 7.5yr8/3, that is a fine grained clay.

P4B The lower 10cm of the core, Hue 5yr 4/6, Hue 7.5yr7/3, that is a medium to course grained sand.

Core 5:

The core is 39 cm deep. The upper 2mm of the sample is a brown sandy layer with salt crystals. The top 10cm of the core is a fine grained clay unit that is a grey to yellow colour. 11-12cm is a 2mm black layer as described in the above core. From 12-20cm a medium grained red sand with the presence of several halite cubes exist. The remainder of the core is a course grained red sand material.

P5A Top 10cm of core, Hue 5yr5/4, Hue 10yr8/3, that is a fine grained clay.

P5B This sample is from 12-20cm, Hue 5yr4/6, Hue 7.5yr7/3, which is a fine grained, clay.

P5C The core is from the lower 10cm of the core, Hue 2.5yr4/8, Hue7.5yr7/4, a medium grained sand.

Core 6:

The depth of the core is 43cm. The upper 12cm of the core is a course brown sand, containing salt crystals of the surface. A dark brown clayish material at a depth of 12-20cm is found. Within this clay are black smears within the clay. The remained or the core is a medium to fine grained red sand that coarsens with depth.

P6A The 10 of the core, Hue 7.5yr5/6, Hue 7.5yr7/3, that is a course grained sand. The salt crystals are course grained and angular.

P6B A depth from 12-20cm in the core, Hue 7.5yr ¾, Hue 7.5yr7/3, that is a fine grained clay.

P6C The lower 10cm of the core, Hue 5yr4/6, Hue 7.5yr7/4, that is fine grained clay to medium grained sand.

Core 7:

The core is 25cm deep. The complete unit is a dark red brown colour that is fine grained, clay. . The lower section of this unit is slightly darker in colour than the upper section. The top 5cm contains come angular salt crystals.

P7A The top 10cm, Hue 7.5yr4/4, Hue7.5yr7/3, a clay, fine grained.

P7B The bottom 10cm, Hue 5yr4/4, Hue7.5yr 7/3, a clay, fine grained.

Core 8:

Thew total depth of the core is 40cm. The upper 2mm is a salt crust, containing crystals that are angular and about 1mm^2, with salt crystals present in the top 10cm. A fine grained clay that is red to brown is found at a depth from 0-28cm. From 28-40cm the core is made up of yellow unit of rock fragments up to 2cm^3, that are held together with a yellow clay matrix.

P8A The top 10cm, Hue 5yr3/4, Hue 7.5yr7/3, a clay, fine grained.

P8B The lower 10cm, Hue 2.5yr5/6, Hue 10yr,6/6, a clay matrix that is fine grained holding angular rocks together.

Core 9:

This core reached a depth of 45cm. The upper 3mm is a hard salt crust, made up of small salt crystals, ~1mm by 1mm. The upper 25 cm is a very clay layer that is light to medium brown in colour, with abundant salt crystals in the upper 15cm. The remainder of the core is dark brown clay layer that has black smears throughout the core.

P9A The upper 10 cm, Hue 7.5yr4/6, Hue10yr8/2, which are clays, fine grained. The salt crust contains course and angular grains of salt, that have hardened.

P9B The lower 10cm, Hue 7.5yr4/4, Hue 10yr7/3, is a fine grained material that is classified as a clay.

Plant up take forms, average soil / plant concentration and toxic concentration of elements analysed by ICPAES. (Berkman 1995; Marschner 1997; Kabata-Pendias 2001). Refer to next page for relative concentrations found in plant substrates.

Element	Forms taken up by plants	Average soil concentration (mg/kg)	Average plant concentration (mg/kg)	Average element excessive /toxic concentration in plants (mg/kg)
Aluminium (Al)	-	4500-90 000	2.6-4470	-
Boron (B)	$H_2BO_3^-$	2-100	0.3-16	>100
Calcium (Ca)	Ca^{2+}	-	5000	-
Chromium (Cr)	Cr^{3+}, Cr^{6+}	5-1000	0.02-0.2	>5
Cobalt (Co)	$Co^{2+,}$ Co^{3+}	1-40	0.05-50	>50
Copper (Cu)	Cu^+,Cu^{2+}	2-100	5-20	>20
Iron (Fe)	Fe, Fe^{2+}, Fe^{3+}	50 000	150	-
Lead (Pb)	Pb^{2+}	2-200	0.1-10	>10
Magnesium (Mg)	Mg^{2+}	1000	300	-
Manganese (Mn)	Mn^{2+}	850	150	>300
Molybdenum (Mo)	MoO_4^{2-}	2	0.33-5	>5
Nickel (Ni)	N^+	5-500	0.1-6.5	>10
Phosphorous (P)	$H_2PO_4^-$, HPO_4^{2-}	100	3000	-
Potassium (K)	K^+	<100	< 5000	-
Sodium (Na)	Na^+	-	3000	-
Sulfur (S)	SO_4^{2-}	1000-2000	30 000	-
Zinc (Zn)	Zn^{2+}, $Zn(OH)_2$	10-300	8-100	>400

Higher or lower concentrations of elements in the soil substrates. Results are compared to world average soil concentrations (previous page). H = higher than average, L = lower than average, - data comparison not available. N = nursery soil, Sand = Sand dune soil, Tailing = average tailing substrate concentrations (pure, and sand dune/tailing treatments).

	Fe	**Mn**	**B**	**Cu**	**Mo**	**Co**	**Ni**	**Zn**
N	L	L	L	L	L	L	L	L
Sand	L	L	L	H	-	H	L	L
Tailing	L	L	L	H	L	H	L	H

	Ca	**Mg**	**Na**	**K**	**P**	**S**	**Al**	**Cd**
N	-	H	-	H	H	H	L	-
Sand	-	H	-	L	L	L	H	L
Tailing	-	-	-	L	L	L	L	-

Mt Gunson Anthropogenic Regolith –Landform Map Units.

Fine sand 125-250µm, Medium sand = ~400-500µm, Coarse sand 500-100µm, Very coarse 1000-2000µm.

Afa1*: Sub-angular medium grained homogeneous quartzose sand. Surface is a very light green ~ 0-5 mm in thickness, upon removal the lower grains show a hue of orange/brown sub-angular sand. No visible vegetation.

Afa2*: Sub-rounded medium grained quartzose sand. Surface is a very light green ~ 0-4 mm in thickness. No visible vegetation. (Possibly relating to old tailing material washing into Gunyah Lake).

Afa3*: Sub angular-rounded sand ~ 300 microns. Surface is transparent to pink (Pandurra), with light green tinge throughout with cementation between grains. No visible vegetation. (Possibly relating to old tailing material washing into Gunyah Lake).

Apd1*: Sub-angular medium grained quartzose sand. Fe-oxide coating on the some quartzose grains. The upper-surface has a distinct green while lower regions are still orange/brown. Salt crusts on some surfaces. No visible vegetation.

Aaw1*: Dominant fine grained brown clay with minor sub-angular quartzose grains. No visible vegetation.

Aaw2*: Fine grained clay-silt, pale green white coloured sediment, with fine-grained sand. No visible vegetation on the tailings.

Aaw3: Fine grained brown clay, with minor sub-angular quartzose grains. No visible vegetation. (Natural Salt Lake Surface).

Aca: Sub-angular-rounded medium grained quartzose sand, red brown sands. Colonised by Chenopod shrubs dominated by *Atriplex vesicaria, Atriplex stipitata, Atriplex spongiosa*, with minor *Eremophila* tree ssp.

Aer1*: Sub-angular medium grained quartzose sand, surface green/purple/yellow, at depth orange/brown. No visible vegetation.

Cer1*: Sub-angular to rounded course grained quartzose sand, white/green sand, with minor, quartzite and secrete material. No visible vegetation.

Cer2*: Sub-angular course grained quartzose sand, white-brown. Dominant quartzite material rock material. No visible vegetation (historic stockpiles in East and West Lagoon).

CHer: Sub rounded fine grained quatzose sand, red brown sand, with rounded gravel and stones mainly quartzite and silcretes. Colonised by Chenopod shrubs dominated by *Atriplex vesicaria, Atriplex stipitata, Atriplex spongiosa*, with minor *Maireana* and *Scleroleana spp.*

Isu1: Sub-rounded medium grained quatzose sands, red brown sands, with occasional courser sands. Colonised by *Acacia aneura, Dodonaea viscosa ssp. angustissima*, *Acacia ligulata, Enchylaena tomentosa* with various *Atriplex spp*.

Ips1: *Sub-rounded medium grained quatzose sands, red brown sands, with occasional courser sands, within low relief areas. Colonised by* Acacia aneura, Acacia papyrocarpa, Acacia ligulata, Dodonaea viscosa ssp. angustissima*, various* Atriplex *spp with the native pine* Callitris columellaris.

SSer: Outcropping quartzose rich Pandurra Formation. Colonised by succulents.

Water bodies*: Copper enriched water.

Tailing Bund*: Sub-rounded medium grained quatzose sand, red brown sand. Making the perimeter of the surface of the tailing.

Old Tailing/Stock Pile*: Black fine-grained course grained, gravel like capping of stockpile/tailings. 15m high.

Disturbed*: Surrounding stockpile, tailings and East and West Lagoon. Medium green on Mt Gunson Anthropogenic Regolith–Landform Map.

*** =** Anthropogenic material, deposited or influenced directly or indirectly by human induced activity.

Regolith

Transported Regolith

A = Alluvial Sediment (Natural and Anthropogenic)

C = Colluvial Sediment (Natural and Anthropogenic)

I = Aeolian Sediment (Natural)

In-Situ Regolith

SS = Slightly weathered bedrock

Landforms

fa = alluvial fan

pd = depositional plain

aw = alluvial swamp

ca = channel deposit

er = erosional rise

su = dune field

ps = sandplain

Mount Gunson Anthropogenic Regolith-Landform Map