Metallophytes on Zn-Pb mineralised soils and mining wastes in Broken Hill, NSW, Australia

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Abstract

The wastes of metalliferous mining activities produce a substrate that is generally unfavourable for normal plant establishment and growth. However, metallophytes have evolved to grow in hostile environments that are rich in metals. They possess key properties that commend them for revegetation of mines and metal-contaminated sites. This field survey aimed to identify native metallophytes occurring on minerals wastes and mineralised outcrops in Broken Hill (New South Wales, Australia). Foliar concentrations of minerals were very high compared with non-mineralised soils but within the range expected for plants in such environments. Neither hyperaccumulators nor obligate metallophytes have been found, but they may be present on isolated mineralised outcrops in the wider Broken Hill area; however, a range of facultative metallophytes was identified in this study. These species could be introduced onto mining leases if establishment protocols for such species were developed.

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Introduction

The wastes from the minerals industry produce environments where plants are exposed to multiple-stresses including phytotoxic metals, adverse physical characteristics of the substrates, salinity, limited nutrient availability and water stress (Ernst 2005; Fellet et al. 2011). Plants with the unique capability to tolerate normally toxic concentrations of metals in their environment are called 'metallophytes' (Baker et al. 2010). Metallophytes can be grouped into two distinct types depending on the nature of their metal uptake characteristics. The first type are plants that limit uptake by the roots and/or restrict the transport of phytotoxic metals to the shoots ('excluders'), whereas the second are plants that accumulate normally phytotoxic metals in their shoots ('indicator', 'accumulator' or 'hyperaccumulator' depending on the shoot metal concentration) (Baker 1981; Baker and Brooks 1989). Most plants are sensitive to metal concentrations in soil and are obligate non-metallophytes (Ernst 1989; Pollard et al. 2002). In contrast, absolute metallophytes are found only on metalliferous soils, whereas, facultative metallophytes have populations on 'normal' and metalliferous soils (Pollard et al. 2002). The evolution of metal tolerance takes place at each specific site because plants are immobile, and therefore have to adapt to survive (Ernst 2006; Baker et al. 2010). Prerequisites for plants to evolve metal tolerance include a substantial genetic variability that allows for selection of 'chemo-ecotypes' (Baker 1987; Ernst 2006). Metal-tolerant ecotypes in populations of common grasses are a well-studied phenomenon of the mineral wastes in Europe (Dechamps et al. 2007, 2011; Remon et al. 2007). Populations of facultative metallophytes may have pronounced intraspecific genetic polymorphisms between tolerant and non-tolerant populations (Deng et al. 2007). The ability of plants to evolve metal-tolerance and colonise mineral wastes does not have to take a long evolutionary trajectory because the selective forces of metal toxicities are unambiguous (Baker 2009). In fact, metal-tolerant ecotypes may evolve quickly, for example, *Mimulus cupriphilus* Macnair (Phrymaceae) evolved from *Mimulus guttatus* DC. in less than 150 years (Macnair 1998). The positive relationship between metal tolerance and available soil metal concentration and steep clines for tolerance at the edges of metal-rich areas (McNeilly and Antonovics 1968) indicate selection against metal tolerance on 'normal' soils (Ernst 2006).

The study of mineral waste colonisation under intense evolutionary selection could lead to insights in the evolution of metal-tolerant species and ultimately contribute to the success of mine rehabilitation (Baker et al. 2010; Erskine et al. 2012). However, contrary to the study of induced re-vegetation of mineral wastes, there has been little focus on the revegetation of minerals wastes by native metallophytes (Craw et al. 2007). Historic mining sites that have been naturally recolonised should, therefore, be seen not just as a liability but also as an opportunity for capturing unique genetic resources (Ginocchio and Baker 2004). Extreme ecosystems are habitats for species 'tailored by evolution' to cope with such circumstances (Bradshaw 1971; Baker 2009). This commends them as the optimal choice for ecological restoration of mineral wastes (Whiting et al. 2004; Baker et al. 2010). However, the properties of metallophytes are often generalised as species, and ecotypes of more common species are often not considered (Baker 1987, 2009). Screening the characteristics for specific ecotypes of metallophytes is vital for studies on metal tolerance mechanisms and their practical applications (Whiting et al. 2004). As a result of the work of Bradshaw and colleagues, several grass cultivars (Poaceae) were developed and made commercially available (Bradshaw 1952, 1960). These included *Agrostis capillaris* 'Goginan' L., *Festuca rubra* 'Merlin' L. and *Agrostis capillaris* 'Parys' L. Despite the long history of research on the development of metal-tolerant cultivars, remarkably little work has been conducted in tropical and semiarid regions.

The Broken Hill ore outcrop is located in New South Wales, Australia and was discovered in 1883 by a local boundary rider (Jones 2011). It was one of the largest surfacing Zn/Pb outcrops in the world (Gustafson et al. 1950). Before mining commenced at the end of the 19th century, the gossan surfaced over 1 km long and was

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3–40 m wide, standing ~50 m above the surrounding landscape and contained up to 25% Pb (Johnson and Klingner 1975). Although the initial surface mineralisation of Broken Hill most likely formed a habitat for metallophytes, virtually nothing is left as a result of extensive mining activities (Figs 1, 2). However, very little is known about the metallophytes of the famous Broken Hill surfacing Zn/Pb ore body. In the period from ~1910–1930, Albert Morris, a local botanist, made extensive collections of plants (~5000 specimens), now stored at the Waite Institute, of the area around Broken Hill (Kennedy 1986). Later, he started the use of some of these species for rehabilitation of the local mine waste areas (Jones 2011). The time span and the extent of metal-rich soils in Broken Hill would undoubtedly have enabled the presence of highly metal-tolerant plants which might still be currently on-site. Therefore, Morris's collections could include metallophytes of the original ore outcrops of the region, as well as a range of plants that grew in the mineralised areas and early mine workings of Broken Hill. Wind-blown dust due to a lack of vegetation was the reason for the extensive rehabilitation efforts of the mineral wastes from the late 1930s onwards by Albert Morris and co-workers (Jones 2011). Plant species introduced during the re-vegetation of the tailings dumps still persist and include *Atriplex nummularia* Lindl. (Atripliceae), now locally dominant, *Cortaderia selloana* Asch. & Graebn., *Cynodon dactylon* (L.) Pers., *Pennisetum clandestinum* Hochst. Ex Chiov. (Poaceae) and *Melaleuca lanceolata* Otto (Myrtaceae) (Thorne and Hore-Lacy 1979). Locally it was observed in 1922 that *Acacia continua* Benth. (Fabaceae) appeared to be restricted to the lode outcrop in Broken Hill (Cole 1965). Furthermore, *Ptilotus obovatus* F.Muell. (Amaranthaceae) and *Prostanthera striatiflora* F.Muell. (Lamiaceae) were recorded to occur commonly over the lode outcrops at Little Broken Hill, Melbourne Rockwell, in the Apollyan Valley, at Angus Mine and at Thackaringa (Cole 1965). *Polycarpaea spirostylis* subsp. *glabra* F.Muell. (Caryophyllaceae) has been noted in the original description of the species to grow especially on lode outcrops (Pedley 1977). Locally called 'Copper Pink', this plant was extensively used by mineral prospectors in the 19th century (Brooks and Radford 1978; Cole and Smith 1984).

The purpose of this study was to survey any putative metal- tolerant plants (metallophytes) growing on the range of a former mine site (mineralised soils and mining wastes) in Broken Hill. The survey was limited to the Line of Lode, Eastern Precinct and North Mine of Perilya Ltd with the objective to identify any plant species in the landscape that may be suitable for closure planning. Specifically, this investigation aims to contribute to the interpretive value for tourism integrated with other aspects of mining heritage tourism at Broken Hill.

Materials and methods

Survey and sample collection

The fieldwork took place in September (main flowering season) at Broken Hill and focused on the Line of Lode remains, the associated mineralisation and mining wastes. Specifically, plant material samples were collected from 19 locations, and soil samples were collected from six locations (four located in the Eastern Precinct, and two in the vicinity of the North Mine (Fig. 3)). During the fieldwork, rhizosphere soil samples (~100 g) and plant foliar samples (~10 g) were collected and analysed for selected elemental concentrations. Soil sampling aimed at indicating if soil Cd-Pb-Zn concentrations were present at phytotoxic levels while plant sampling intended to discover plants that may accumulate these specific elements. The climate of Broken Hill is semiarid with an annual rainfall of 230 mm with a winter peak, and the temperatures fluctuate from a minimum mean of 6C in winter to a maximum mean of 33oC in summer.

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Foliar sampling and chemical analysis

Foliar samples were collected from occurring plant species in conjunction with parallel herbarium vouchers specimens for identification purposes. The leaves were thoroughly washed with demineralised water immediately after collection to remove potential dust contamination as much as possible and were subsequently dried at 70C for 2 days. Subsamples were digested with 4 mL 70% HNO_3 and 1 mL 30% H_2O_2 in a microwave (Milestone Start D) and diluted to 30 mL before analysis.

Soil sampling and chemical analysis

Soil samples were collected from the rhizosphere of plants sampled for foliar material, dried to constant weight and sieved to <2 mm. Subsamples (0.3 g) were digested with 9 mL 37% HCl and 3 mL 70% HNO3 on a hot block (140C) for 3 h and diluted to 40 mL with deionised water to determine the total trace element concentrations. Soil pH and electrical conductivity was obtained in a 1 : 2.5 soil-water mixture after 1 h equilibrium time on an end-over-end shaker and 1 h settling time. Plant- available phosphorus as Olsen-P was extracted with 1.0 g soil extracted with 20 mL 0.5 M NaHCO3 (pH 8.5) for 30 min (Olsen 1954). Plant-available phosphorus ('ML-3') was also extracted with Mehlich-3 solution (0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA at pH 2.50 ± 0.05) (Mehlich 1984). This method is also used for phytoavailable trace elements, and as such provides a 'multifunctional' extract. Potentially phytoavailable trace elements (Ni, Co, Cr and Mn) were extracted with Diethylene triamine pentaacetic acid (DTPA) (Lindsay and Norvell 1978). All digests and extracts were analysed with ICP-AES (Varian Vista Pro II) for Ni, Co, Cu, Zn, Mn, Fe, Mg, Ca, Na, K, S and P. The ICP-AES instrument was calibrated using a six-point multi-element standard (which included all measured elements) prepared in each extraction solution.

Results

Vegetation survey on mineralised soil and mining wastes

The dominant vegetation, particularly on overburden waste dumps and tailings facilities, includes a range of common species and weeds. Particularly dominant are some species of saltbush (*Atriplex nummularia, A. lindleyi, Arthrocnemum halocnemoides* – Atripliceae). Common exotic weed species including velvet mesquite (*Prosopis velutina* – Fabaceae), athel pine (*Tamarix aphylla* – Tamaricaceae), peppercorn tree (Schinus molle – Anacardiaceae), oleander (*Nerium oleander* – a characteristic species-assemblage, of which floristic elements were also present in other parts of Perilya's Ltd mining lease. These plants included *Isotoma petraea* (Campanulaceae), which might be characteristic for surface mineralisation in the primary habitat, albeit not restricted to mineralised soils (Wiecek 1992).

Soil chemistry of the Zn-Pb lode

The main physico-chemical characteristics of the soils are presented in Table 1. The alkaline pH of the soils (7.2–8.7) results from the carbonated nature of the rocks from which the soils derive. The total and extractable concentrations of the major and trace elements of interest are shown in Tables 2 and 3. Most major element concentrations (Ca, K, Mg and Na) are highly heterogeneous. Only P and Fe concentrations vary within a limited range. Pb and Zn concentrations in the soils are extremely high, indicating surface mineralisation and contamination as a result of mining activities. Both measures of bioavailability (DTPA and Mehlich) are extremely high relative to normal soils, and also relative to other metalliferous soils elsewhere. The concentrations of bioavailable Zn and Pb are in the phytotoxic ranges (Kabata-Pendias 2011), which means that plants growing in these soils need to have specific metal tolerance to survive and reproduce. The higher values in the Mehlich extracts can be explained by the chemical form (likely as easily dissolved carbonate and

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hydroxides) in which Zn-Pb are hosted. There is a positive correlation between total soil Pb and Zn and Mehlich-extractable Pb and Zn (Pb r2 0.84 and Zn r2 0.98) (Fig. 4). Some other trace- element total and extractable-concentrations such as Cd, Cu and Mn are relatively high.

Analysis of plant material

The plant foliar elemental concentrations are listed in Tables 4 and 5. Although the concentrations of Zn are relatively high in most plant samples, these values are within the expected range of plants growing in Zn-mineralised soils (Lottermoser et al. 2008). Lead concentrations are generally much lower than Zn concentrations; this not only reflects the lower average Pb concentrations in the soil, but the much lower

Discussion

The total Zn and Pb concentrations are extremely high in the soils sampled at Broken Hill. Furthermore, the potentially bioavailable Zn and Pb concentrations, as measured in DTPA and Mehlich extracts, are also very high. Therefore, any plants growing in these soils are metal-tolerant (and hence ‘metallophytes’). The range of native metallophytes (grasses, herbs and shrubs) falls into the category of ‘facultative metallophytes’ as no species is restricted solely to Zn-Pb mineralised soils. The foliar Zn and Pb concentrations are within the range expected for plants growing on mineralised soils and very high compared with non-mineralised soils. However, none are ‘hyperaccumulators’, but rather are ‘bioindicators’ and ‘excluders’ (mainly the grasses).

bioavailability (as indicated by the DTPA and Mehlich-3 extracts) of this metal to uptake by plants. Nevertheless, Pb concentrations in plants are relatively high. However, none of the plants collected and analysed are hyperaccumulators of either of these metals (i.e. >3000 mg g^{-1} foliar Zn or >1000 mg g^{-1} foliar Pb; van der Ent et al. 2013). Several of the sampled plants fall in the ‘indicator’ category with the moderately high uptake of Zn and/or Pb, relating to the soil concentrations of these metals. Others, particularly the grasses, are typical ‘excluders’ with low metal content in the biomass regardless of soil metal concentrations. Regarding other elements of interest, Cd concentrations in plants are rather high but no species could be considered a potential hyperaccumulator, while Cu and Mn concentrations do not show signs of accumulation. It is important to note that the results for some plant samples might be inaccurate as a result of contamination with dust on very hairy and/or resinous leaf surfaces, despite thorough washing before analysis. This factor is difficult to exclude entirely, except in pot trials in a greenhouse where metal-rich dust can be excluded entirely (Faucon et al. 2007).

Vegetation has been used to find ore deposits for centuries based on the observation that some plant species are found on mineralisation (Cannon 1960; Dunn 2011). However, the vegetation on Broken Hill has been profoundly disturbed due to clearing, burning and overgrazing for over 50 years, making any geobotanical studies practically impossible (Cole 1965). Since the 1960s, other noteworthy geobotanical investigations have been conducted in Australia on sites similar to Broken Hill. These surveys include sites in the Mount Isa inlier (Dugald River area, which is one of the world largest Zn-Pb- Cu deposit and three gossans 200 km south of Cloncurry) located in north-western Queensland and the Bulman- Waimuna Springs area located in the southern part of Arnhem Land in Northern Territory (Nicolls et al. 1965; Cole et al. 1968). At the Dugald River outcrop, a unique plant assemblage occurs over the Zn-Pb-Cu lode and surrounding metalliferous sites (Nicolls et al. 1965). Zinc is not an essential factor in the local plant assemblage and did not have a significant influence unless Pb or Cu concentrations were simultaneously high. The ‘lode’ assemblage includes *Polycarpaea spirostylis* subsp. *glabra* (Caryophyllaceae), *Eriachne mucronata* and *Fimbristylis* sp. nov. (Poaceae), *Tephrosia* sp. nov. (Fabaceae) and *Bulbostylis barbata* (Cyperaceae) (Nicolls et al. 1965). As for the Bulman locality, Zn-Pb mineralisation is hosted in limestone in a savanna woodland environment (Cole

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et al. 1968). Few trees are found in this area, which is characterised by a metallophyte assemblage composed of *Polycarpaea syn*andra var. *gracilis* and *Gomphrena canescens* (Amaranthaceae), both confined to the mineralised area where the soil concentration in Zn is greater than 50 000 mg g^{-1} and Pb reaches 5000 mg g^{-1}. *Gomphrena canescens* accumulates substantial amounts of Zn with more than 135 000 mg g–1 in the ash or 13 500 mg g–1 DW in the leaves, when growing over mineralised soil, whereas Polycarpaea synandra var. gracilis from the same site can accumulate over 80 000 mg g^{-1} in the ash or 6900 mg g^{-1} DW in the leaves (Cole et al. 1968). However, uncertainty remains on the accuracy of the reported values as contamination with soil dust particulates cannot be excluded. Notable similarities between both sites are observed in the distribution of the *Polycarpaea* and *Tephrosia* genera related to the elemental anomalies, in the occurrence of the same grass species (*Eriachne mucronata*) over the Zn value down scarp from the footwall of the lode or in the presence of *B. barbata* (Cole et al. 1968). A survey of three gossans in the Mt Isa Inlier describes a lode assemblage dominated by *E. mucronata, Enneapogon lindleyanus* and *Paraneurachne muelleri* (Poaceae) together with, depending on the site, plants confined to the gossan area including *Hybanthus aurantiacus* (Violaceae), *Clerodendrum tomentosum* (Verbenaceae) and *B. barbata* (Lottermoser et al. 2008). All of these plants have a high level of tolerance to Cd, Cu, Pb or/and Zn, and thus can be defined as metallophytes. Bulbostylis barbata is also found near the Cu smelter at Mount Morgan whereas *P. spirostylis* occurs at several contaminated sites in the Mount Isa–Cloncurry region (Cole and Smith 1984). It is noteworthy that all of the metallophytes are facultative and widespread on other non- mineralised (skeletal) soils (Cole 1965).

From the viewpoint of mine site rehabilitation, metal-tolerant ecotypes of grasses are the most useful group of plants, and not only need to be metal-tolerant, but also drought resistant, able to establish on poorly-structured substrates, and tolerant of major nutrient deficiencies (Tibbett 2015). The use of such metal-tolerant ecotypes is a proven strategy for mine site rehabilitation on Zn-Pb-rich substrates (Tordoff et al. 2000; Grant et al. 2002; Whiting et al. 2004). In Europe, metal- tolerant ecotypes have been bred to commercial cultivars specifically for reclamation of ‘difficult’ mineral wastes (Tordoff et al. 2000). Capitalising on the unique ability of metallophytes to tolerate adverse soil conditions should be part of successful rehabilitation strategy (Bolan et al. 2017). The re-vegetation of mineral wastes in Broken Hill goes back to Albert Morris’ work from 1936 onwards, mainly to combat dust problems (Jones 2011).

In most circumstances, the legislatory framework for mine rehabilitation aims to restore sites to historical ecosystems (Hobbs and Cramer 2008). This involves the use of native seed banks, soil improvements technics or landscape redesigning (Huang et al. 2012). An atypical approach using the natural-novel ecosystems paradigm has gained interest lately (Erskine and Fletcher 2013; Perring et al. 2014). The core of this framework is that novel ecosystems bridge the conceptual gap dividing under-rehabilitated area and re-instated ‘historical’ ecosystems (Doley et al. 2012). It bounds decision makers to set realistic rehabilitation objectives (Hobbs et al. 2006). Three options exist: the first aims to restore the site to the extent of its historical succession trajectory; the second aims to include features from the past landscape with novel attributes; while the last option leads to the creation of an entirely novel environment, preferably created with native plant species (Erskine and Fletcher 2013).

Pioneer native species play a fundamental role in the rehabilitation efforts by developing suitable habitats for the establishment of native flora. However, some (exotic) species can arrest ecological succession if no management is undertaken and substantially alter the target ecosystem (Firn et al. 2013). One of the main challenges is, therefore, to increase the relative abundance of native and adapted species over abundant invasive weeds. The Broken Hill area could be considered of high conservation importance similar to the lead mining remains of the Peak District in England (Barnatt and Penny 2004). Indeed, what was once one of the

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greatest, richest and longest-mined ore fields in Australia contributes to the regional major landscape of which metallophytes form an integral part. Although, obligate metallophytes have not been found in this study, further research focusing on metallophytes growing on isolated mineralised outcrops in the wider area should be prioritised to assist in their conservation and possible utilisation in rehabilitation efforts at Broken Hill.

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FIGURES AND TABLES

Fig. 1. Relics of the original ore outcrop of the ‘Line of Lode’ near North Mine: view of outcrop looking North from Jamieson’s shaft as it appeared in 1886 (a), view of the Broken Hill Proprietary Co. Limited site in the late 19th century (b), recent view of the Round hill lode outcrop (c), view of the Rasp’s shaft as it appeared in 1883 (d). Historical images courtesy of Brian Tonkin of the Broken Hill ‘Outback Archive’.

Fig. 2. Relics of the original ore outcrop of the ‘Line of Lode’ near North Mine with highly metal-tolerant grasses (facultative metallophytes): outcropping gossans near the Browne’s shaft at Junction mine (a), smaller isolated outcrop near the Browne’s shaft at Junction Mine (b), closer prospect of *Isotoma petraea* growing between cracks of an exposed gossan at the corner of Menindee Road and the path to Junction Mine (c), outcropping gossans at the corner of Menindee Road and the path to Junction Mine (d). Photographs by Antony van der Ent.

Fig. 3. The location of plant and soil samples in Broken Hill and the layout of the city.

Fig. 4. Total soil concentrations of Zn and Pb versus Mehlich extractable concentrations (mg g^{-1}). Circles mark Pb and triangles mark Zn.

Table 1. General properties of the collected soils from Broken Hill.

Table 2. Total soil element concentrations of the collected soils from Broken Hill (major elements).

Table 3. Total and extractable soil element concentrations of the collected soils from Broken Hill (trace elements).

Table 4. Macro elements in plant material (mg g^{-1} and weight (wt) % as indicated). Exotic (weed) species are indicated: *

Table 5. Trace elements in plant material (mg g^{-1}). Exotic (weed) species are indicated: *

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FIGURE 1

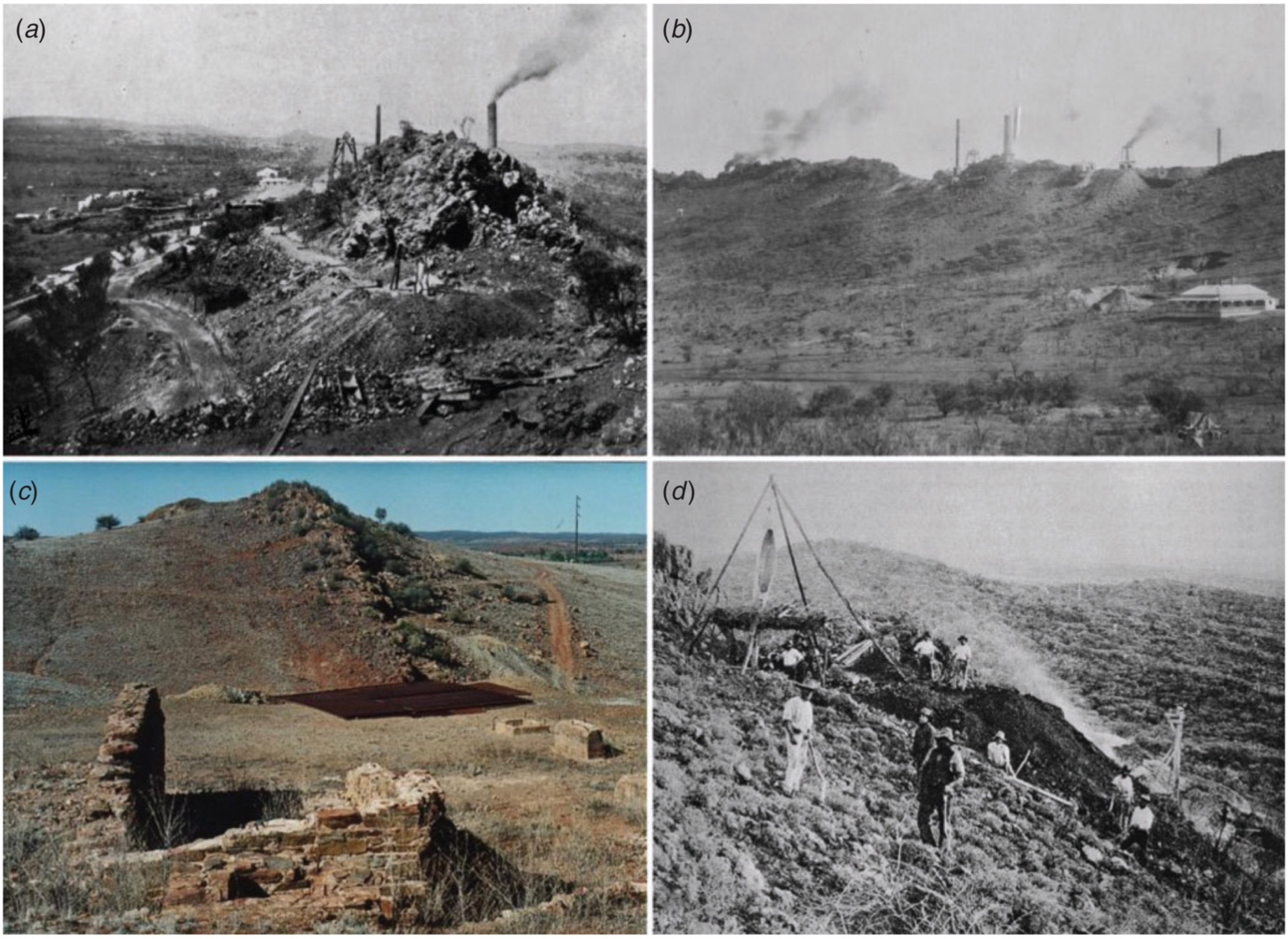

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FIGURE 2

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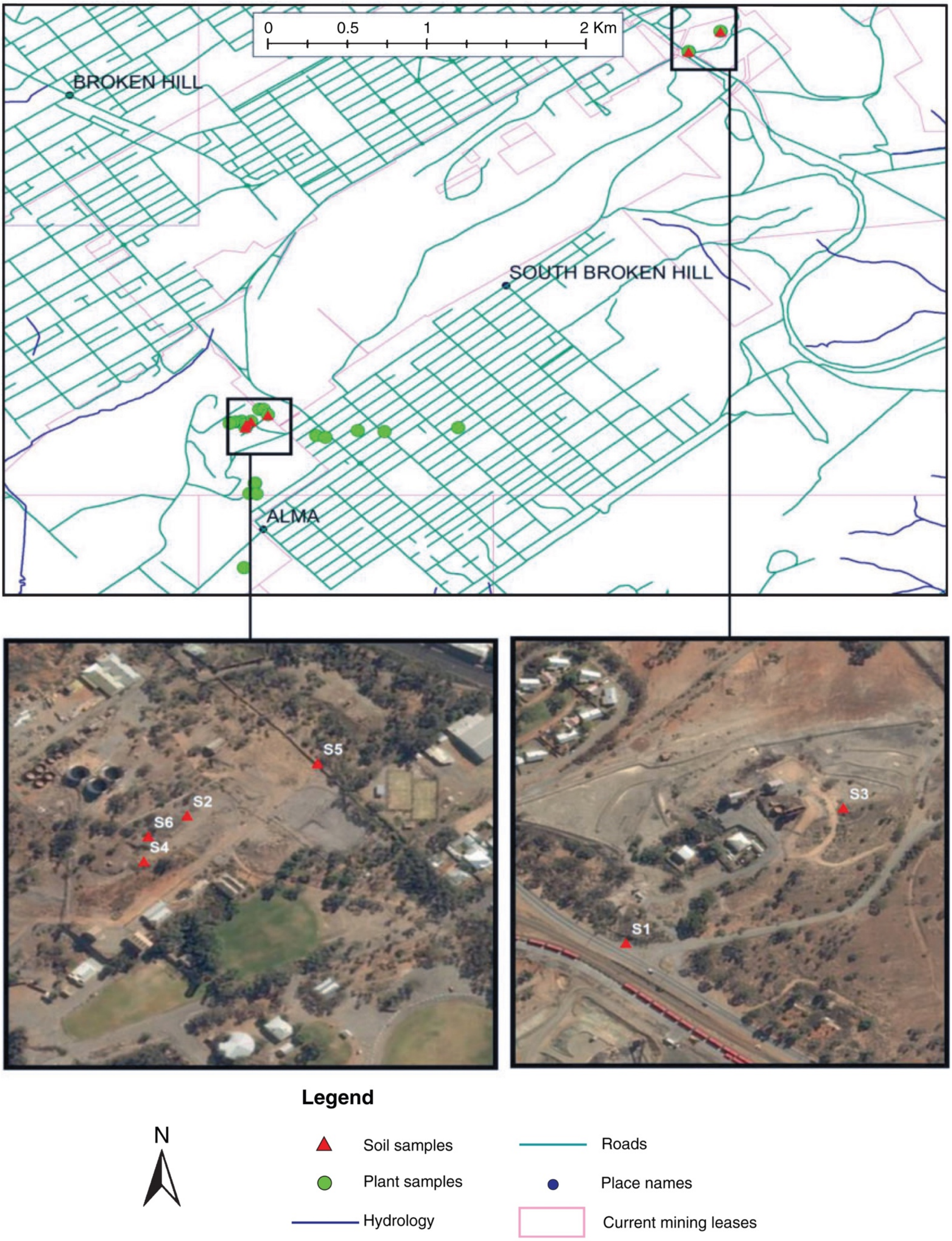
FIGURE 3


0
0.5
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BROKEN HILL
SOUTH BROKEN HILL
ALMA
S5
S2
S6
S4
S3
S1
Legend
N
Soil samples
Plant samples
Hydrology
Roads
Place names
Current mining leases

TABLE 1 + 2

Properties	Soil					
	S1	S2	S3	S4	S5	S6
pH	7.3	7.2	7.9	8.0	8.7	5.5
Conductivity (dS m^{-1})	0.26	0.81	0.08	0.18	0.06	2.19

Element	Unit	Soil					
		S1	S2	S3	S4	S5	S6
Ca	mg g^{-1}	5.45	20.9	10.9	11.6	15.6	8.20
Fe	mg g^{-1}	8.90	15.6	11.6	13.8	13.8	14.1
K	μg g^{-1}	976	312	831	340	285	896
Mg	μg g^{-1}	625	566	743	595	787	218
Na	μg g^{-1}	85.4	29.8	31.6	17.9	60.3	50.6
P	mg g^{-1}	1.39	1.86	1.61	1.37	1.95	0.31

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TABLE 3

Element	Extraction	Soil					
		S1	S2	S3	S4	S5	S6
Cd	Total $\mu g\ g^{-1}$	23.4	73.1	18.8	41.6	48.7	10.1
	DTPA $\mu g\ g^{-1}$	3.46	4.15	2.65	3.40	1.81	3.04
	Mehlich-3 $\mu g\ g^{-1}$	6.79	9.62	5.18	7.05	6.93	4.03
Cu	Total $\mu g\ g^{-1}$	211	718	200	1700	459	212
	DTPA $\mu g\ g^{-1}$	8.30	7.06	6.46	37.3	2.17	17.4
	Mehlich-3 $\mu g\ g^{-1}$	25.1	38.2	22.2	143	19.0	47.3
Mn	Total $\mu g\ g^{-1}$	4510	7390	7630	8730	5550	1780
	DTPA $\mu g\ g^{-1}$	2.86	0.16	0.47	0.10	0.55	5.68
	Mehlich-3 $\mu g\ g^{-1}$	69.8	69.9	79.4	47.8	78.4	42.7
Pb	Total $\mu g\ g^{-1}$	9000	30 000	7170	18 500	5550	4080
	DTPA $\mu g\ g^{-1}$	290	305	550	545	270	611
	Mehlich-3 $\mu g\ g^{-1}$	937	1700	1260	1590	794	907
Zn	Total $\mu g\ g^{-1}$	9110	31 800	8890	29 500	19 700	1660
	DTPA $\mu g\ g^{-1}$	337	364	288	272	364	252
	Mehlich-3 $\mu g\ g^{-1}$	1960	5850	1920	3790	3137	532

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TABLE 4

Family	Taxa	Cd	Cu	Mn	Pb	Zn
Amaranthaceae	_Ptilotus obovatus_	20.2	61.6	612	162	668
Amaranthaceae	_Ptilotus obovatus_	12.3	11.7	264	363	805
Amaranthaceae	_Tecticornia_ sp. undetermined	18.7	4.03	66.8	25.8	178
Asphodelaceae	_Asphodelus fistulosus_*	11.2	4.68	91.2	32.4	278
Asteraceae	_Brachyscome debilis_	28.9	12.2	56.7	124	455
Asteraceae	_Leiocarpa_ sp. undetermined	12.0	26.9	109	157	435
Asteraceae	_Leiocarpa tomentosa_	27.9	34.5	327	303	920
Asteraceae	_Leiocarpa tomentosa_	6.09	17.1	60.2	121	351
Asteraceae	_Sonchus asper_*	13.3	24.3	84.3	469	758
Adenosine triphosphateliceae	_Atriplex nummularia_	15.9	6.83	81.2	81.3	513
Boraginaceae	_Echium plantagineum_*	3.66	13.4	89.4	53.7	913
Campanulaceae	_Isotoma petraea_	2.18	3.92	619	68.5	695
Campanulaceae	_Isotoma petraea_	4.15	3.24	625	20.6	589
Cupressaceae	_Callitris preissii_	2.08	5.82	252	58.9	577
Fabaceae	_Acacia aneura_ var. _tenuis_	0.17	8.30	93.6	102	278
Fabaceae	_Daviesia_ sp. undetermined	2.12	11.0	44.1	113	161
Fabaceae	_Daviesia_ sp. undetermined	4.21	3.76	99.8	156	198
Fabaceae	_Senna artemisioides_ subsp. _artemisioides_	4.25	16.1	84.3	69.0	380
Fabaceae	_Senna artemisioides_ subsp. _artemisioides_	3.69	7.59	41.6	146	338
Fabaceae	_Senna artemisioides_ subsp. _artemisioides_	9.85	3.57	30.1	43.7	107
Fabaceae	_Senna artemisioides_ subsp. _filifolia_	3.44	6.75	27.2	25.7	332
Malvaceae	_Hibiscus_ sp. undetermined	2.94	7.98	181	52.2	176
Myrtaceae	_Eucalyptus camaldulensis_	1.65	6.31	115	70.9	335
Myrtaceae	_Eucalyptus largiflorens_	0.93	5.85	207	46.2	67.5
Myrtaceae	_Eucalyptus sideroxylon_	6.83	22.9	379	64.2	268
Myrtaceae	_Eucalyptus_ sp. undetermined	2.35	12.5	99.8	341	351
Myrtaceae	_Melaleuca lanceolata_	1.00	6.37	83.8	45.1	88.4
Papaveraceae	_Argemone ochroleuca_ subsp. _ochroleuca_*	2.20	13.4	77.7	358	607
Poaceae	_Enneapogon polyphyllus_	2.64	16.6	117	514	415
Poaceae	_Pennisetum setaceum_*	15.6	12.0	86.2	137	360
Scrophulariaceae	_Eremophila longifolia_	5.15	26.6	52.9	65.5	454
Scrophulariaceae	_Myoporum montanum_	4.26	14.8	40.0	24.4	117
Solanaceae	_Solanum ellipticum_	2.98	7.91	81.2	71.4	268
Solanaceae	_Solanum sturtianum_	3.39	7.58	73.0	68.8	307
Solanaceae	_Solanum sturtianum_	5.78	24.0	456	291	549

ACCEPT

TABLE 5

Family	Taxa	Cd	Cu	Mn	Pb	Zn
Amaranthaceae	*Ptilotus obovatus*	20.2	61.6	612	162	668
Amaranthaceae	*Ptilotus obovatus*	12.3	11.7	264	363	805
Amaranthaceae	*Tecticornia* sp. undetermined	18.7	4.03	66.8	25.8	178
Asphodelaceae	*Asphodelus fistulosus**	11.2	4.68	91.2	32.4	278
Asteraceae	*Brachyscome debilis*	28.9	12.2	56.7	124	455
Asteraceae	*Leiocarpa* sp. undetermined	12.0	26.9	109	157	435
Asteraceae	*Leiocarpa tomentosa*	27.9	34.5	327	303	920
Asteraceae	*Leiocarpa tomentosa*	6.09	17.1	60.2	121	351
Asteraceae	*Sonchus asper**	13.3	24.3	84.3	469	758
Adenosine triphosphateliceae	*Atriplex nummularia*	15.9	6.83	81.2	81.3	513
Boraginaceae	*Echium plantagineum**	3.66	13.4	89.4	53.7	913
Campanulaceae	*Isotoma petraea*	2.18	3.92	619	68.5	695
Campanulaceae	*Isotoma petraea*	4.15	3.24	625	20.6	589
Cupressaceae	*Callitris preissii*	2.08	5.82	252	58.9	577
Fabaceae	*Acacia aneura* var. *tenuis*	0.17	8.30	93.6	102	278
Fabaceae	*Daviesia* sp. undetermined	2.12	11.0	44.1	113	161
Fabaceae	*Daviesia* sp. undetermined	4.21	3.76	99.8	156	198
Fabaceae	*Senna artemisioides* subsp. *artemisioides*	4.25	16.1	84.3	69.0	380
Fabaceae	*Senna artemisioides* subsp. *artemisioides*	3.69	7.59	41.6	146	338
Fabaceae	*Senna artemisioides* subsp. *artemisioides*	9.85	3.57	30.1	43.7	107
Fabaceae	*Senna artemisioides* subsp. *filifolia*	3.44	6.75	27.2	25.7	332
Malvaceae	*Hibiscus* sp. undetermined	2.94	7.98	181	52.2	176
Myrtaceae	*Eucalyptus camaldulensis*	1.65	6.31	115	70.9	335
Myrtaceae	*Eucalyptus largiflorens*	0.93	5.85	207	46.2	67.5
Myrtaceae	*Eucalyptus sideroxylon*	6.83	22.9	379	64.2	268
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Myrtaceae	*Melaleuca lanceolata*	1.00	6.37	83.8	45.1	88.4
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Poaceae	*Enneapogon polyphyllus*	2.64	16.6	117	514	415
Poaceae	*Pennisetum setaceum**	15.6	12.0	86.2	137	360
Scrophulariaceae	*Eremophila longifolia*	5.15	26.6	52.9	65.5	454
Scrophulariaceae	*Myoporum montanum*	4.26	14.8	40.0	24.4	117
Solanaceae	*Solanum ellipticum*	2.98	7.91	81.2	71.4	268
Solanaceae	*Solanum sturtianum*	3.39	7.58	73.0	68.8	307
Solanaceae	*Solanum sturtianum*	5.78	24.0	456	291	549

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