Rehabilitation of Extreme Chemical Substrates on Mine Sites Without Soil in a Semiarid Climate, New Zealand

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Abstract

Observations from six historic placer gold mines in southern New Zealand have shown that soil-free impermeable clay-rich substrates develop evaporative salt encrustations, leading to elevated electrical conductivity (EC>1 mS/cm) and locally elevated pH (7-10.5). Endemic halophytic plants can tolerate these extreme conditions, and enhance local biodiversity. High EC excludes competing plants. Part of our research project has been a two-year pilot study to physically remove areas of encroaching sediment and weeds to expand the bare substrates and facilitate halophyte colonisation. This approach is a viable option for enhancing biodiversity on mine sites with extreme chemical environments.

Keywords: Evaporite, Rehabilitation, Gold, Alkaline, Saline, Ecosystem, Halophyte

Introduction

Most mine sites expose abundant bare rock during development, and some rehabilitation is required. Many sites have rock components that generate extreme chemical conditions at the surface, such as acid rock drainage, and this hinders revegetation efforts. Hence, most such sites are rehabilitated by addition of a soil cover. This can be effective, but is expensive and leads to uniform landscape with low biodiversity and potential weed problems. We report here on a novel alternative approach for small areas of this type of mine site, where bare ground is maintained as habitat space, with extreme chemical compositions at the surface, with establishment of specialist plants that can tolerate such environments to enhance local biodiversity.

Observations from six historic (century-old) placer gold mines in southern New Zealand (Fig. 1a) have shown that soil-free impermeable substrates develop evaporative salt encrustations in a regional rain shadow (Fig. 1b) where annual rainfall is <400 mm. These substrates are clay-altered schist basement (Fig. 1c) that was exposed when sediments containing placer gold were removed by historic mining activities. Most of these sites have been naturally colonised by endemic halophytic plants, probably from local coastal environments, that can tolerate these extreme conditions, and rely on these conditions to exclude competing plants. These endemic halophytes constitute a rare and endangered ecosystem that has been incorporated into several reserves for conservation purposes (Craw *et al.* 2021a,b; 2022a,b). However, wind-borne and water-borne permeable sediment incursion on to these bare saline substrates, allows weeds to progressively colonise the saline substrates and develop organic soil (Rufaut *et al.* 2018; Craw and Rufaut 2021; Craw *et al.* 2021a). In this pilot study, we describe the effects of clearance of weeds and permeable sediments to allow natural recolonisation of impermeable substrates and enhancement of the rare ecosystems.

Methods

The pH and EC of bare mine substrates were obtained in the field a portable Oakton PC450 meter on slurries made with 20 ml of solids and 30 ml of added distilled water. Leachate compositions from substrate samples were obtained by placing 200 mL of substrate in 2-litre plastic bottles for 1 week. Leachates were analysed for major ions at

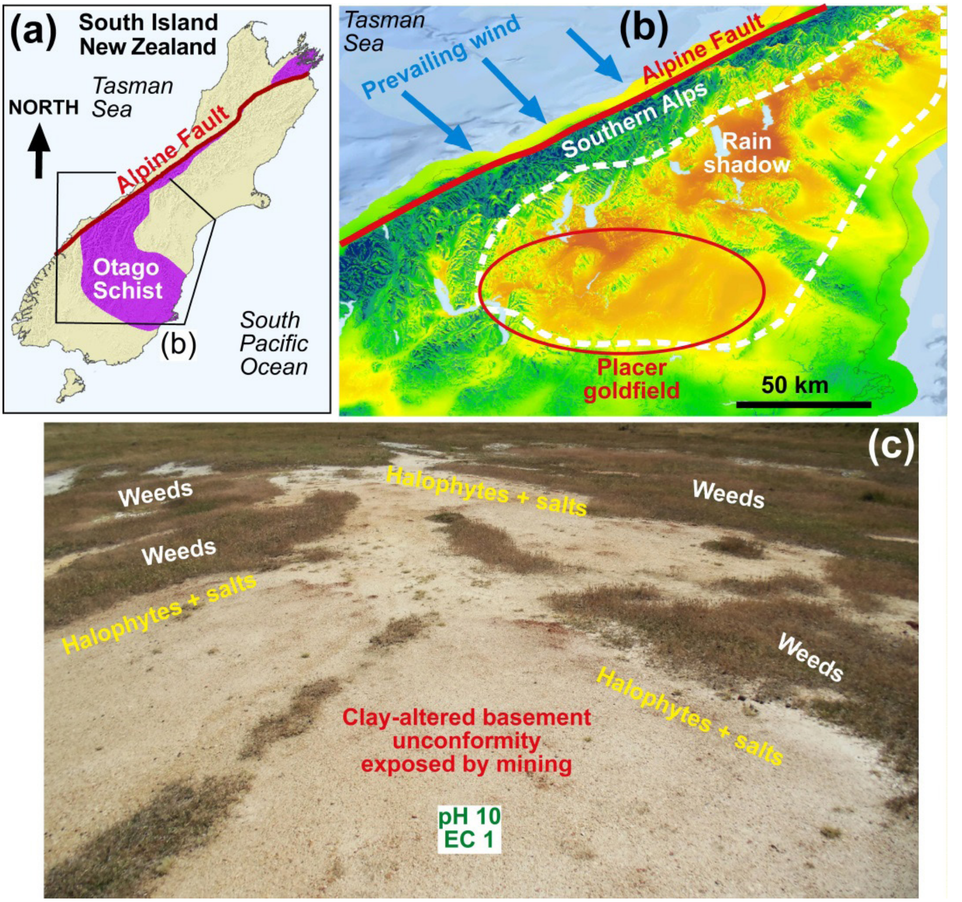

Figure 1 *Location and setting of placer gold mine bare substrates in this study. (a) Regional geological setting. (b) Location of placer goldfield in rain shadow in lee of Southern Alps mountains, shown with relative solar irradiation (from Solargis; http://globalsolaratlas.info). (c) Example of unrehabilitated placer gold mine site with saline substrate (EC in mS/cm) and halophytes. Site has been abandoned for a century, but encroaching weeds are reducing the saline areas.*

Eurofins, Christchurch, New Zealand, an IANZ-accredited commercial laboratory. Identification of minerals in salt encrustations was done with scanning electron microscopy (SEM) with energy dispersive analytical attachment at the Otago Micro and Nanoscale Imaging (OMNI), University of Otago. Some mineral identifications were augmented with X-ray diffraction (XRD).

Pilot studies of saline substrate enhancement were carried out at several sites by removing weeds and exposing clay-rich bare substrates. Halophytes were present adjacent to these plots, and in the general vicinity, and these plants were allowed to naturally colonise the cleared plots.

Chemistry and mineralogy of the bare substrates

The saline impermeable substrates at the studied gold mines have elevated electrical conductivity (EC >1 mS/cm) and most have elevated pH (7-10.5) as summarised in Fig. 2a. Salinity is provided by evaporation of rainwater with dissolved marine aerosols (Fig. 2b; Druzbicka *et al.* 2015; Craw *et al.* 2021a,b; 2022a). Winter surface water activity can lead to lowering surface salt contents, while salts are rapidly replaced in spring. Salts include NaCl, Na-carbonates, Na-sulfates, and Ca-carbonates. Interaction between surface and shallow groundwater and the underlying

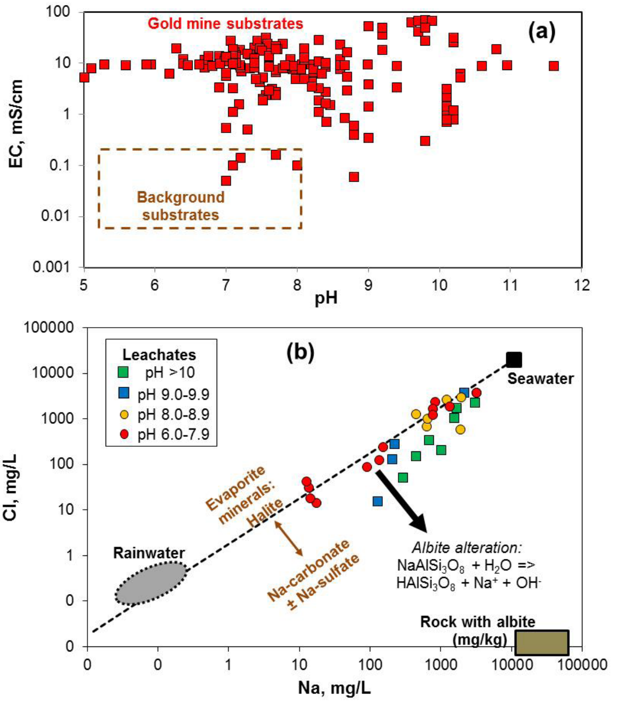

Figure 2 *Surface geochemistry of saline substrates in the placer goldfield. (a) EC and pH data for saline bare substrates at six placer gold mine sites. (b) Leachates from saline bare substrates, showing compositions in relation to variably diluted seawater, and pH rise as a result of interaction with albite in substrates (equation from Mamonov et al. 2020).*

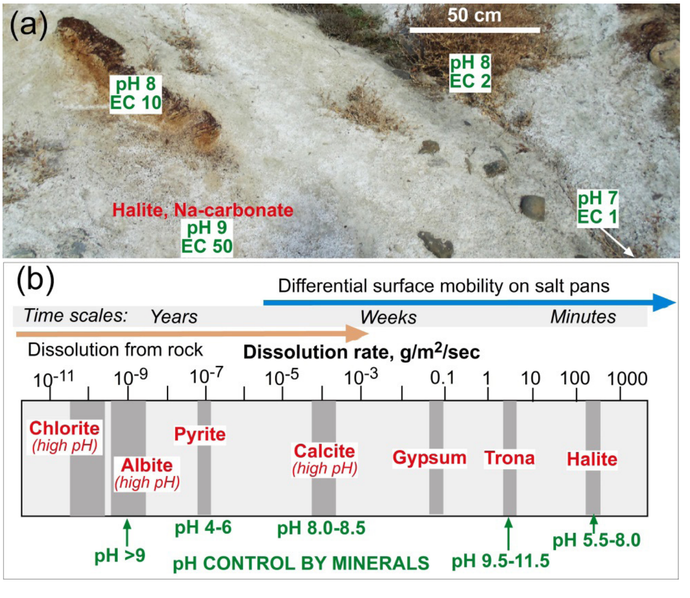

Figure 3 *Mineral variations in and on placer mine substrates, and related pH and EC. (a) Example of evaporative salts and associated local variations of pH and EC (in mS/cm) at a placer mine site. (b) Relative dissolution rates of key minerals in substrates (left) and on salt pans (right) and the associated pH. Modified from Craw et al. (2022a) with data from references cited therein.*

substrates locally causes increases in pH as a result of albite alteration (Fig. 2b). The resultant elevated Na facilitates precipitation of Na-carbonates, with associated elevated pH (Fig. 2b; 3a,b). In addition, elevated Na causes precipitation of Na-bearing sulfates (Fig. 2b, 3b). Alteration of pyrite in the substrates and remnant sediments can lower pH locally (Fig. 2a).

Chemistry and mineralogy of the substrates are highly variable on small scales (Fig. 3a) as a result of differential mobility of different minerals in surface waters. Alteration of rock-forming minerals occurs on a time scale of years and controls the chemistry of shallow groundwaters that slowly pass through the substrates (Fig. 3b), facilitated by evaporative capillary action. In contrast, occasional rain events result in ephemeral surface waters that mobilise evaporative minerals at different rates on time scales of minutes to weeks (Fig. 3b).

Redevelopment of impermeable clay substrates

In this pilot study, irregular areas of a few tens of square metres were cleared of weeds and permeable sediment that had encroached on the clay substrates left by the miners when the sites were abandoned (Fig. 4a). Clearance was done in winter, and the sites were left to naturally consolidate through the following spring. The sites were checked regularly for colonisation by halophytes from adjacent ground. Care was taken to produce plots with a naturalised appearance that connected through to adjoining impermeable subsrtate.

Previous work on these sites has shown that halophytes are typically established on substrates with EC >1 mS/cm, with no clear pH controls (Fig. 1c; Rufaut *et al.* 2018; Craw and Rufaut (2021). The EC and pH of the redeveloped substrates in this study were highly variable because of the extensive

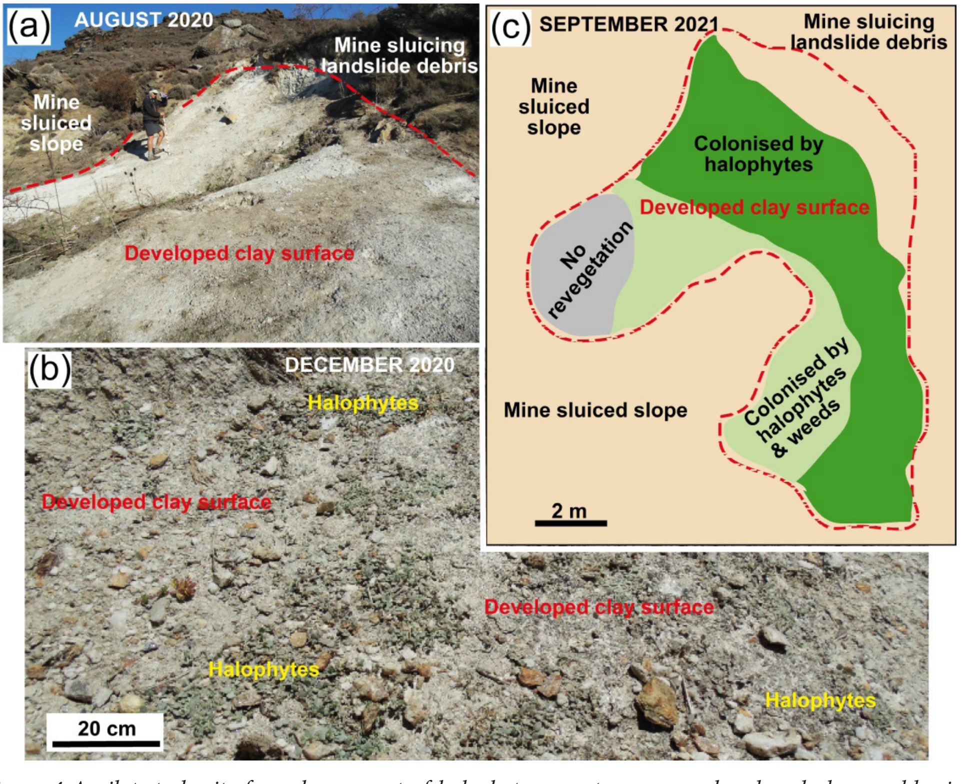

Figure 4 A pilot study site for enhancement of halophyte ecosystem on an abandoned placer gold mine. (a) Photo of part of site after initial excavations. (b) Initial colonisation of halophytes. (c) Map of site after a year, showing distributions of colonising plants.

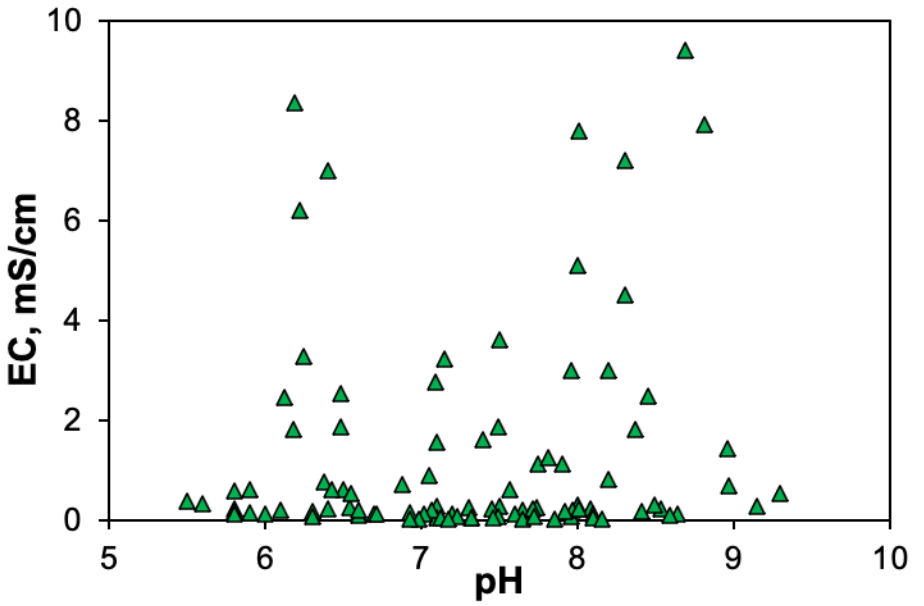

Figure 5 *EC and pH measurements on redeveloped mine substrate surfaces in the placer mining area in which the Fig. 4. pilot study was carried out. Data were gathered over two years as the surfaces consolidated and were partially recolonised by halophytes.*

disturbance of the clearing activity, and some parts persisted with EC <1 mS/cm. However, most of the sites became progressively more saline with time, and local EC values exceeded 8 mS/cm (e.g., Fig. 5) and irregular salt encrustations developed.

Halophyte colonisation was remarkably rapid at most of the studied sites, and initial colonisation had occurred within a few months in the first spring (Fig. 4b). Colonisation continued over the following year, with the coverage by halophytes extending and becoming denser. After the first year, substantial recolonisation had occurred (e.g., Fig. 4c).

Conclusions

Addition of soil to bare rock surfaces at mine sites is a common rehabilitation procedure, and likely to remain so for most sites. However, our study shows that in an arid climate, impermeable bare mine substrates can be rehabilitated without addition of soil. Development of evaporative salts created a geochemically distinct environment in which halophytic plants can thrive, while excluding other plant species that are not salt-tolerant. This situation enhances biodiversity at the sites. Some additional management may be required periodically, as incursion of more permeable sediment can facilitate colonisation of weeds, shrinking the areas of bare substrates. Our pilot study shows that engineered removal of this encroaching sediment, and weeds, can enhance mine rehabilitation with halophytes. Similar approaches may be possible for rehabilitation of mine sites elsewhere in the world, wherever geochemically extreme substrates are exposed that favour tolerant plant species. This approach requires acceptance by stakeholders that the persistence of bare ground is an advantage, not a disadvantage.

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