Erosional and Geochemical Controls on Natural Revegetation at an Unremediated Placer Gold Mine, Central Otago, New Zealand

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ABSTRACT

The abandoned Springvale placer gold mine sits in the toe of a complex Quaternary alluvial fan in the rain shadow of the Southern Alps of New Zealand. Biogeochemical maps and SEM analysis of the sediments and evaporative salts quantify the relationships controlling the natural revegetation of the site over the past ~100 years. Historically, miners sluiced auriferous gravels down mine channels to extract gold, leaving highly variable yet small-scale topography (net 20 m of relief) and impermeable mudstone exposed. On this mudstone, evaporative salts (calcite, gypsum, and halite) crystallize due to the semi-arid climate and a saline input dominantly from marine-derived aerosols in the rain. Repeated weathering events concentrate the salts down-slope into planar fans of mudstone runoff (1-10 m^2), with conductivities generally >1,000 µS and reaching >20,000 µS. Salt-tolerant plants (halophytes) colonize these runoff fans without encroaching up the adjacent mudstone outcrops, which is partly due to the compaction of the mudstone versus the open microstructure of the recycled sediment. The halophytes are rare and endangered, so the New Zealand Department of Conservation protected the site as a scientific reserve. Adventive plants are outcompeted by the halophytes in the saline runoff fans and instead only colonize gravel-rich mine tailings (conductivity <1,000 µS).The sharp control imparted by the geomorphology and substrates leads to a natural and biodiverse revegetation of the site. The use of varied landscapes and substrates to support biodiversity should be applied during active remediation of other mine sites.

REGIONAL SETTING

- The Springvale gold mine is one of many saline sites in alluvial fans in Central Otago, but it is the only one on mudstone (Fig. 1B,C)
- Central Otago is a basin and range region in the south central part of the Southern Island of New Zealand (Fig. 1A,B)
- It is in the rain shadow of the Southern Alps, an active mountain range along the west coast of the Southern Island of New Zealand (Fig. 1A)

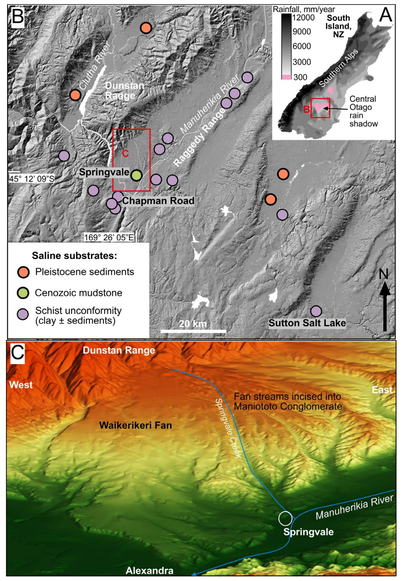

Fig. 1. Regional setting of Springvale Scientific Reserve, Central Otago.

A. Central Otago is in the rain shadow from the Southern Alps along the western coast of the South Island of New Zealand. Contoured rainfall map is modified from NIWA 2015.

B. Hillshade image with principal saline sites located in the NE-SW striking series of Central Otago's folded ridge and valley topography.

C. Pleistocene Waikerikeri Fan emanating from the rising Dunstan Range into the Manuherikia Valley. Springvale sits along bottom perimeter of the fan. Oblique digital image has 2x vertical exaggeration.

RESULTS OF MINING

- Placer gold was mined from Springvale by washing Quaternary conglomerates down mine channels, exposing basal gold and silcrete boulders (quartz pebbles cemented by dissolved silica) (Fig. 2)
- The mine site was left unremediated for ~100-150 years, and this left impermeable mudstone exposed with variable topography (Fig. 2,3)
- Erosion from the mudstone is deposited as planar fans, which become salinized and support salt-tolerant (halophyte) plant populations (Fig. 3)

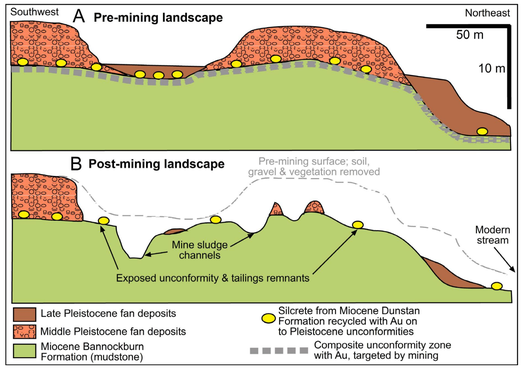

Fig. 2 (Left) Stratigraphic cross-sections through Springvale showing: **A.** the inferred depositional landscape and **B.** the current post-mining landscape along the same section line. Exaggerated vertical scale.

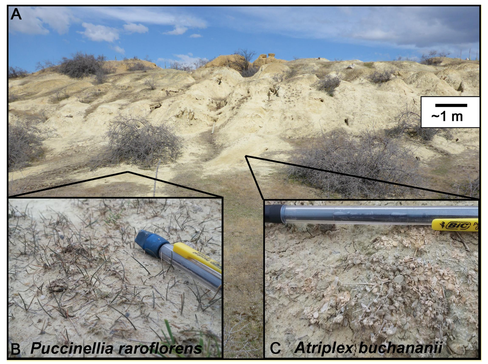

Fig. 3. (Right) A. Bare, impermeable mudstone exposed at Springvale by historic mining with fans of current runoff along the base of the exposure. Remnants of Early Pleistocene gravels (orange/tan unit) can be seen along top of Miocene Bannockburn mudstone. On the saline runoff fans grow two halophyte (salt-tolerant) species (**B and C**).

BIOGEOCHEMICAL MAPPING

The following maps were constructed using on-site observations and aerial photographs. Sediment samples were tested in a laboratory setting.

Geologic Map

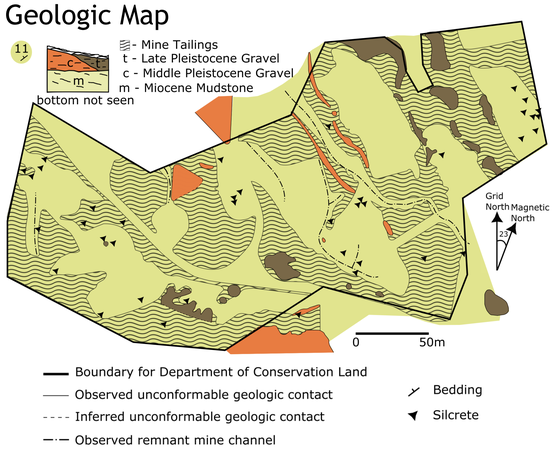

Fig. 4. (above) Geologic map of Springvale Scientific Reserve, Central Otago.

Vegetation Map

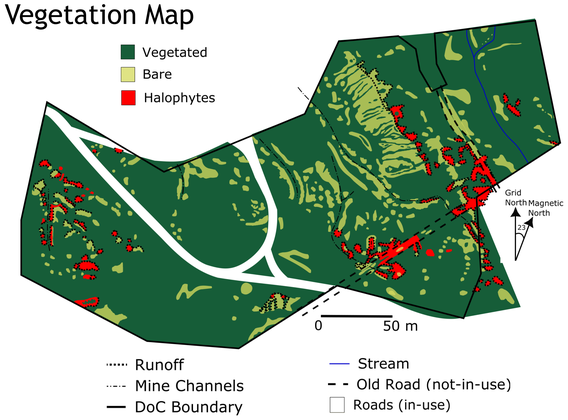

Fig. 5. (above) Vegetation map of Springvale Scientific Reserve, Central Otago.

Water Flow Map

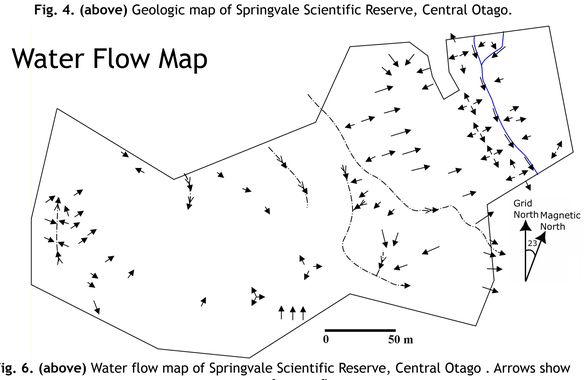

Fig. 6. (above) Water flow map of Springvale Scientific Reserve, Central Otago . Arrows show vectors of water flow.

Conductivity Map

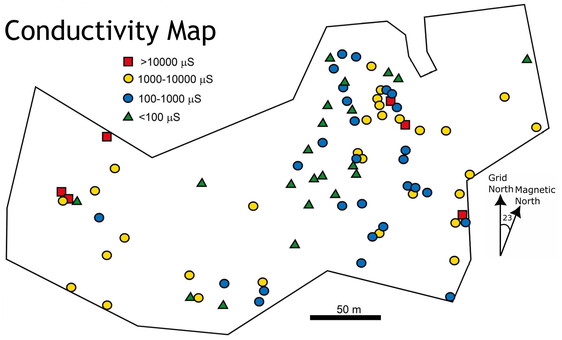

Fig. 7. (above) Conductivity map of Springvale Scientific Reserve, Central Otago. Each colored shape represents a sediment sample that was tested for conductivity and pH, but only conductivity (µS) is represented here.

SEDIMENT ANALYSIS

- Sediment samples across all geologic and vegetation distinctions were tested for conductivity and pH (Fig. 8)
- A SEM was used to view in-tact sediment chucks from a runoff fan (Fig. 9) and the bare mudstone
- The surfaces of runoff fans are comprised of a loose microstructure, contain minimal clay particles, and host diverse salts (gypsum, calcite, and halite) (Fig. 9)
- The surfaces of bare mudstone are compacted and host less diverse salts (mostly halite)

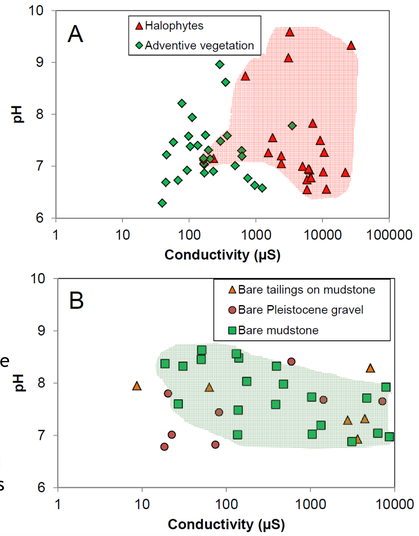

Fig. 8 (Above) pH vs. Conductivity plots for sediments of varying geologic derivation and with different vegetation distinctions.

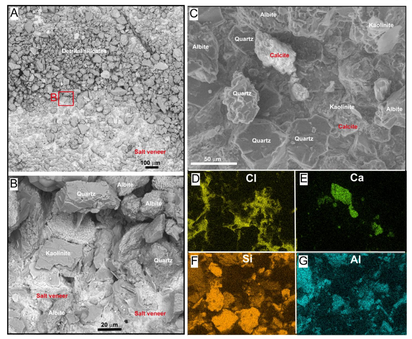

Fig. 9 (Left) *SEM data*. **A,B,C** Detrital sediment on surface of runoff fan with evaporative salts. **D,E,F,G** Chemical maps of image C with Cl representing halite, Ca representing calcite, Si representing silicates (quartz, albite, kaolinite), and Al highlighting albite.

CONCLUSIONS

- Halophytes populate runoff fans (Fig. 5), which develop down-slope of bare exposures of mudstone (Fig. 4, 6) and have high salinity (conductivity >1,000 µS) (Fig. 7,8A).
- Heavy weedy vegetation (Fig. 5 – green) populates areas of pebble-rich mine tailings (Fig. 4), which also have lower conductivities (conductivity <1,000 µS) (Fig. 7, 8A).
- Planar fans of mudstone runoff have greater surface texture and diversity of salts (halite, calcite, gypsum) than bare mud-cracked mudstone (Fig. 9).
- **Diverse landscapes and substrates at mine sites can lead to naturally increased biodiversity and should be incorporated into modern mine remediation.**

ACKNOWLEDGEMENTS

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