Journal of Geochemical Exploration 137 (2014) 11–28

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

journal homepage: www.elsevier.com/locate/jgeoexp

Identification of acid rock drainage sources through mesotextural classification at abandoned mines of Croydon, Australia: Implications for the rehabilitation of waste rock repositories

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ARTICLE INFO

Article history:
Received 16 January 2013
Accepted 31 October 2013
Available online 9 November 2013

Keywords:
Acid drainage
Static tests
Mineralogy
Texture
Sulphide oxidation

ABSTRACT

Developing effective strategies to manage acid rock drainage (ARD) from historic and abandoned mine sites is a significant rehabilitation challenge. In Australia, there are more than 50,000 recorded abandoned mine sites, many of which have associated ARD and water quality issues. Traditional rehabilitation strategies focus on utilising a blanket approach to management. However, if sources of ARD were instead thoroughly characterised, cost-effective management strategies based on mineralogy could be formulated, potentially enhancing site rehabilitation and ensuring longer-term success.

A mesotextural method was developed to domain waste rocks into groups based on their mineralogical, textural and chemical similarities, using routine geological tools and field-based analytical instrumentation. This was tested at the abandoned mining operations at Croydon, North Queensland, from which uncapped sulphidic waste rock piles were sampled. Surface water and sediment samples collected from creeks up to 10 km downstream of the site showed elevated concentrations of As, Cd, Cu, Ni, Pb, S and Zn relative to local background levels, indicating the necessity for effective rehabilitation strategies to be implemented at these sites. Ten mesotextural waste rock groups (A to J) were identified in the piles across both mine sites and comprise of hydrothermally altered rhyolites, and massive sulphides. Three major sulphide-bearing groups were identified (G, H and J). Mineralogical and geochemical data indicated that group J (quartz–pyrite) was acid forming, with pyrite containing significant concentrations of As, Pb, Zn and Cu. Pyrite was in early weathering stages with some hydrous ferric oxides observed on grain rims and fractures. Group H (arsenopyrite–quartz–pyrite) was also acid forming; with scorodite extensively precipitated in fractures and rims, likely retarding arsenopyrite oxidation. Significant quantities of Zn and Cd were leached from Group G (quartz–sphalerite–galena) in first flush experiments, and were also measured downstream of the Glencoe site (at which the majority of group G material was identified). Microtextural analyses showed galena had partial weathering to anglesite, suggesting a potential Pb source. High concentrations of Fe and Cd (8.5 wt.% and 0.19 wt.% respectively) were measured in sphalerite, which likely encouraged oxidation, and subsequent release of Zn. Considering the diversity of the sulphide mineralogy and the associated weathering pathways, a rehabilitation strategy which focuses on segregating waste on the basis of mesotextural classification should be considered.

1. Introduction

Effective management of acid rock drainage (ARD) is a significant rehabilitation challenge for abandoned mine sites. At these sites, the exposure of sulphides to water, air and microorganisms, leads to oxidation and ARD generation (Egiebor and Oni, 2007; Evangelou and Zhang, 1995). Under these acidic conditions, liberation of dissolved components including heavy metals (e.g., Cd, Co, Cu, Hg, Ni, Pb and Zn) and metalloids (e.g., As, Sb) is promoted (Ashley et al., 2004; Plumlee, 1999). Once metals enter streams, complex pH and redox dependant processes (including transformation, speciation and complexation) influence the transport and fate of metals and determine their concentrations in both surface and subsurface environments (Caruso and Bishop, 2009). Subsequently, aquatic and terrestrial ecosystems downstream of mine works are at risk of significant environmental degradation (David, 2003; Gray, 1997; Hudson-Edwards and Edwards, 2005; Luís et al., 2009).

In Australia, there are over 50,000 registered abandoned mines which range from isolated minor surface works, to large and complex sites (Franco et al., 2010; Unger et al., 2012). Features of these sites can include waste rock piles, tailings storage facilities, mineral

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http://dx.doi.org/10.1016/j.gexplo.2013.10.017

processing wastes, and remains of mining infrastructure. Abandoned waste rock piles are significant sources of ARD (cf. Ashley et al., 2004; Aykol et al., 2003; Harris et al., 2003; Lottermoser et al., 2005; Marescotti et al., 2007; Mudd, 2005; Smuda et al., 2007; Tarras-Wahlberg and Nguyen, 2008). Current mining practices dictate that waste rock piles are engineered based on geochemical classifications, with waste rock classes or types defined by acid forming/neutralising characteristics (e.g., Andrina et al., 2006; Brown et al., 2009; Hutchison and Brett, 2006; Smith et al., 2009, Tran et al., 2003). However, at abandoned mine sites, waste rock piles were not constructed in this manner (Ashley et al., 2004; Harris et al., 2003; Hudson-Edwards and Edwards, 2005; Lottermoser et al., 1999), with costs of remediating associated ARD estimated at AUD$100,000 or more per hectare (Harries, 1997). Current rehabilitation strategies are responsive in their nature (i.e., only implemented if acid rock drainage occurs). Consequently, a 'blanket approach' to management is adopted whereby techniques such as lime dosing and waste rock capping are implemented, but have mixed success (e.g., Edraki et al., 2009, 2012; Gasparon et al., 2007; Gore et al., 2007; Mudd and Patterson, 2010). Alternatively, undertaking detailed and effective predictive characterisation on an individual site basis may allow for the breakage of source–pathway–receptor chains (Vik et al., 2001), and improve rehabilitation long-term.

The objective of this study was to develop a systematic approach to characterising waste rock pile materials and identifying ARD sources at abandoned mine sites. Therefore, a mesotextural classification method based on mineralogical and textural differences observed in hand-specimen samples to define waste rock groups is proposed. The method was tested at the abandoned Croydon gold mines, north Queensland, Australia, from which ARD (pH < 4) is emanating as measured through a local geochemical study of sediments and surface waters. Following mesotextural grouping, samples were subjected to ARD predictive tests according to the geochemistry–mineralogy-texture (GMT) approach proposed in Parbhakar-Fox et al. (2011). This contribution demonstrates that through adopting a systematic mesotextural classification scheme, ARD sources are readily identified and can be prioritised for remediation as part of an effective long-term rehabilitation plan.

2. Croydon mining area

2.1. Mining history

The Croydon gold mining district is located approximately 15 km northeast of the Croydon Township and 400 km northeast of Mt. Isa, north Queensland (Fig. 1). Small-scale historic mining of reef gold was undertaken in the 1880 to 1890s, and modern open pit mines targeted 2.84 Mt of ore (3.4 g/t Au) from 1981 to 1991 at two main sites: Federation/La Perouse and Glencoe (Van Eck and Child, 1990). The mine workings and waste rock piles have remained undisturbed since 1991. Currently, the Department of Natural Resources and Mines are in management of this site, with estimated rehabilitation liabilities of AUD $1.8 million for the waste rock piles alone (DME, 2008).

2.2. Physiography and climate

The region has a tropical savannah type climate with an average annual rainfall of 750 mm, much of which falls between December to March. The average annual temperature is 33.8 °C, with maximum temperatures experienced during November to January (Fig. S1; Bureau of Meteorology, 2013). Tabletop Creek and Deadhorse Creek drain the Federation/La Perouse and Glencoe sites respectively (Fig. 1). Deadhorse Creek is a tributary of Tabletop Creek, with the confluence approximately 10 km from the mining operations. Tabletop Creek is in turn a tributary of the Carron River, which flows into the Gulf of Carpentaria. Much of the Croydon district is used for grazing, including the immediate mine area (DME, 2008).

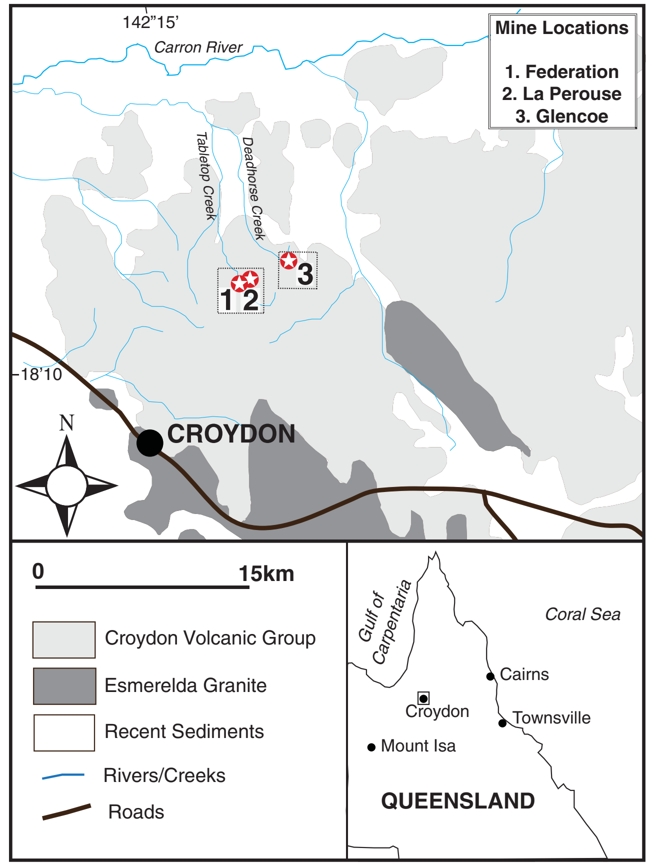

Fig. 1. Simplified geology of the Croydon area showing locations of abandoned gold mine sites (after Bain et al., 1998).

2.3. Geology and mineralisation

The geology of the Croydon district is dominated by the Mesoproterozoic rhyolitic Croydon Volcanic Group (CVG) and Esmerelda Supersuite (Fig. 1). The Croydon lode gold deposits are hosted by the CVG, which is overlain by the Gilbert River Formation. The lodes consist of major quartz, potassium feldspar, muscovite, plagioclase, minor illite, kaolinite, sulphides (pyrite, arsenopyrite, sphalerite, galena), and traces of pyrrhotite and chalcopyrite (Van Eck and Child, 1990).

The CVG has been subjected to varying degrees of hydrothermal alteration, with evidence of silicification, kaolinitisation and sericitisation observed in wall rock adjacent to the quartz veins (Van Eck and Child, 1990). In terms of acid forming potential, the host rocks to mineralisation have little potential for buffering acid produced from sulphide oxidation, as carbonates are notably absent. Effective silicate neutralising minerals (e.g., biotite, chlorite and serpentinite) as defined by Bowell et al. (2000) and Jambor et al. (2002) are also absent.

2.4. Site description

The Federation/La Perouse site consists of two pits (Federation: 320 m × 160 m × 35 m; and La Perouse: 270 m × 180 m × 40 m), two waste rock piles (Federation/La Perouse pile: 1.5 million m^3 and 35,000 m^3), one stockpile (25,000 m^3), heap leach pads (55,000 m^3), a catch dam (170 m × 65 m), a seepage collection pond (100 m × 30 m) and relict mining infrastructure including a crusher platform. The waste rock piles comprise materials ranging from boulder (>0.5 m diameter) through to coarse sand crushings (0.2–1 cm) and abundant fines (<0.2 cm). The entire waste rock piles comprise approximately 70% flow-banded rhyolite, 20% red-stained rhyolites and tuffs, and 10% quartz–sulphide vein material (DME, 2008). Most of this material displays