Nitrate release from waste rock dumps in the Elk Valley, British Columbia, Canada

Fazilatun N. Mahmood a, S. Lee Barbour b, C. Kennedy c, M. Jim Hendry a,*

a Department of Geological Sciences, University of Saskatchewan, 114 Science Place, Saskatoon, SK S7N 5E2, Canada
b Department of Civil, Geological and Environmental Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK S7N 5A9, Canada
c SRK Consulting (Canada) Inc., 22nd Floor, 1066 West Hastings Street, Vancouver, BC V6E 3X2, Canada

HIGHLIGHTS
• Blasting at mines is an important but understudied source of nitrate.
• NO₃ and its stable isotopes were analyzed on waste rock samples and water samples.
• NO₃ concentrations in fresh blast and aged rock are highly variable.
• Field scale leaching efficiency is 80–90%.
• In most cases, NO₃ flushing from dumps will take several decades.

GRAPHICAL ABSTRACT

ABSTRACT

The origin, distribution and leaching of nitrate (NO₃⁻) from coal waste rock dumps in the Elk Valley, British Columbia, Canada were defined using chemical and NO₃⁻ isotope analyses (δ¹⁵N- and δ¹⁸O-NO₃⁻) of solids samples of pre- and post-blast waste rock and from thick (up to 180 m) unsaturated waste rock dump profiles constructed between 1982 and 2012 as well as water samples collected from a rock drain located at the base of one dump and effluent from humidity cell (HC) and leach pad (LP) tests on waste rock. δ¹⁵N- and δ¹⁸O-NO₃⁻ values and NO₃⁻ concentrations of waste rock and rock drain waters confirmed the source of NO₃⁻ in the waste rock to be explosives and that limited to no denitrification occurs in the dump. The average mass of N released during blasting was estimated to be about 3–6% of the N in the explosives. NO₃⁻ concentrations in the fresh-blast waste rock and recently placed waste rock used for the HC and LP experiments were highly variable, ranging from below detection to 241 mg/kg. The mean and median concentrations of these samples ranged from 10–30 mg/kg. In this range of concentrations, the initial aqueous concentration of fresh-blasted waste rock could range from approximately 200–600 mg NO₃⁻-N/L. Flushing of NO₃⁻ from the HCs, LPs and a deep field profile was simulated using a scale dependent leaching efficiency (f) where f ranged from 5–15% for HCs, to 35–80% for the LPs, to 80–90% for the field profile. Our findings show aqueous phase NO₃⁻ from blasting residuals is present at highly variable initial concentrations in waste rock and the majority of this NO₃⁻ (>75%) should be flushed by recharging water during displacement of the first stored water volume.

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* Corresponding author.
E-mail addresses: fam651@mail.usask.ca (F.N. Mahmood), lee.barbour@usask.ca (S.L. Barbour), c kennedy@srk.com (C. Kennedy), jim.hendry@usask.ca (M.J. Hendry).

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1. Introduction

Elevated nitrate (NO$_3^-$) concentrations in groundwater or surface water can cause health problems in humans (Kross et al., 1993; Comly, 1987; Johnson et al., 1987). As such, the maximum drinking water concentration for NO$_3^-$ is 10 mg NO$_3^-$-N/L (WHO, 2004; Health Canada, 2014; U.S. EPA, 2009). In British Columbia, Canada, the average and maximum guideline concentrations for fresh water aquatic life are set at 3 and 33 mg NO$_3^-$-N/L, respectively (Nordin and Pommern, 2009).

Elevated NO$_3^-$ concentrations in natural waters are generally attributed to diffuse or point sources associated with the use of fertilizer or biological waste from agriculture or municipal sources (Power and Schepers, 1989; Hallberg, 1989; Seiler et al., 1999; Wakida and Lerner, 2005). However, a much less studied source of NO$_3^-$ is nitrogen (N) release associated with the use of explosives to blast rock during mining operations. The primary blasting agent used by the mining industry is ammonium nitrate (NH$_4$NO$_3$) mixed with fuel oil, often referred to as ANFO (94–98% NH$_4$NO$_3$ + 2–6% fuel oil). In the USA, 69% of all explosives sold in 2013 were used in the coal mining industry (USGS, 2013). NH$_4$NO$_3$ is highly soluble in water and dissociates into NO$_3^-$ and NH$_4^+$. In alkaline environments, NH$_4^+$ further dissociates to NH$_3$ from explosives during mining is usually attributed to NH$_4$NO$_3$ spillage or incomplete detonation and subsequent dissolution (Cameron et al., 2007; Pommern, 1983). In spite of the widespread use of ANFO and its potential release to receiving surface and groundwater, detailed studies of the distribution and controls on NO$_3^-$ in stockpiled waste rock are few (Bailey et al., 2013; Ferguson and Leask, 1988; McDonald, 1987; Pommern, 1983). Further, we are aware of no studies that address the long-term leaching of ANFO derived NO$_3^-$ from full-scale waste rock dumps or the hydrogeochemical controls on blasting derived NO$_3^-$ within these dumps.

The Elk Valley Watershed in southern British Columbia, Canada (Fig. 1a) is a major source of steelmaking coal in Canada (Goodarzi et al., 2009). Coal mining in the valley began around 1897 with large-scale open-pit coal mining beginning in the 1960s. Currently, there are five open-pit steelmaking coal-mining operations in the Valley: Coal Mountain Operation (CMO), Elkview Operation (EVO), Line Creek Operation (LCO), Greenhills Operation (GHO), and Fording River Operation (FRO) (Fig. 1b). These mines use conventional open pit drill and blast methods, and truck and shovel technology. The total waste rock generated by these operations by 2010 was approximately 4.7 billion bank cubic meters (BCM) (Teck EVWQP Annex D.4, 2014). Most of the waste rock is deposited in dumps, typically by end dumping. The average dump thickness within the Elk Valley is > 100 m. The majority (95–100%) of this waste rock consists of interburden siltstones and mudstones and thin, un-minable coal seams of the Mist Mountain Formation (Gibson and Hughes, 1981; Vessey and Bustin, 2000).

During the early 1960s and 1970s, the mean background N (NO$_3^-$ - N + NO$_2^-$ - N) concentrations measured in the Elk River south of Sparwood (Fig. 1b) were < 0.01 mg/L (McDonald, 1987; Clark and Peppin, 1984). These concentrations began to increase in the early 1980s (Ferguson and Leask, 1988; McDonald, 1987; Pommern, 1983). Ferguson and Leask (1988) attributed the source of NO$_3^-$ to N-based explosives used in rock blasting. The increasing concentrations of NO$_3^-$ in the Elk River with time have also been positively correlated with the volume of waste rock production (Strategic Advisory Panel on Selenium Management, 2010).

The objectives of this study were to: (1) characterize and quantify the source(s) of NO$_3^-$ in coal waste rock in the Elk Valley, British Columbia; (2) define the geochemical controls exerted on NO$_3^-$ within the dump; and (3) characterize the long-term leaching of NO$_3^-$ from the dump. The objectives were attained by analyzing waste rock samples collected from the parent (pre-blasted) rock, fresh-blasted (< 10 d old), and aged waste rock from an existing dump (deposited between 1982 and 2012). The evolution of NO$_3^-$ release in porewater from humidity cell (HC) and leach pad (LP) experiments were also compared to the NO$_3^-$ concentrations in water samples collected from a rock drain located at the base of a dump.

The current study is part of a multi-disciplinary research program initiated by Teck Coal in 2012 to improve our understanding of the
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