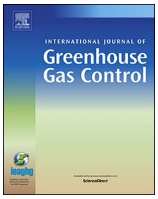
International Journal of Greenhouse Gas Control 63 (2017) 392–400

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

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



Ambient mineral carbonation of different lithologies of mafic to ultramafic mining wastes/tailings – A comparative study

Ali Entezari Zarandi[a], Faïçal Larachi[a,*], Georges Beaudoin[b], Benoît Plante[c], Michelle Sciortino[d]

[a] Department of Chemical Engineering, Université Laval, Québec, QC G1 V 0A6, Canada
[b] Department of Geology and Geological Engineering, Université Laval, Québec, QC G1 V 0A6, Canada
[c] Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, Québec J9X 5E4, Canada
[d] RNC Minerals, Toronto, ON M5J 2W4, Canada

ARTICLE INFO

Keywords:
CO_2 sequestration
Mineral carbonation
Nesquehonite
Stability
Ambient conditions
Ultramafic tailing

ABSTRACT

Four lithologies of the Dumont nickel project were studied for assessing the carbonation capacity in ambient conditions of waste rocks and mineral processing tailings consisting of dunite, peridotite, gabbro, and volcanic materials. Mineral carbonation of these mine waste and tailing minerals is contemplated as a premium solution to permanently trap atmospheric CO_2 into solid carbonates using a differential batch carbonation cell and carbonate precipitation columns. The different mafic to ultramafic lithologies of the Dumont nickel project were characterized before and after carbonation by means of X-ray diffraction and thermogravimetry analyses, Fourier transform infrared spectroscopy, optical microscopy, and quantitative evaluation of minerals by scanning electron microscopy. It was found that for identical size fractions, carbonation of rock wastes was quite limited as compared to the tailings. Brucite more abundant in dunite and peridotite substrates was found to be the main reactant involved in carbonation as compared to other less-reactive magnesium silicate minerals. Nesquehonite, the prevalent magnesium carbonate species formed in wet ambient carbonation, remained stable despite prolonged exposition in dry ambient air conditions. Finally, some design recommendations were formulated to overcome the dilemma due to separate storage of high-permeability brucite-poor (lowly reactive) waste rock stockpiles, and finely-ground low-permeability brucite-rich (highly reactive) tailings.

1. Introduction

As ore is mined and subjected to comminution processes through a suite of mineral processing operations for the separation of the valuable concentrates produces, a mass of finely ground particles is produced. This process is essential to the liberation of the valuable economic minerals, the non-economic residues of which produces as fine grained mineral mass, termed mine “tailings”. The access to ore requires clearing waste rocks which are another byproduct of mining operations in which non-economical surrounding rocks and overburden material are removed. While waste rocks are mainly composed of coarse grained materials, tailings consist of very fine particles potentially offering superior reactivity owing to their larger specific surface area. Therefore, long-term carbon dioxide (CO_2) storage in ultramafic mine tailings and waste rocks is considered as an environmentally and economically viable approach in response to the global warming concerns. Passive mineral carbonation is a thermodynamically favorable process which exploits Nature’s enabling conditions to store atmospheric carbon dioxide with mafic/ultramafic minerals in the form of stable and environmentally benign carbonate minerals (Manning et al., 2013).

Starting from mining and industrial residues, tremendous efforts are being deployed to implement and optimize carbon capture and storage solutions at an industrial scale to permanently sequester atmospheric CO_2 as stable mineral carbonates. Studies included the effect of environmental parameteres on passive mineral carbonation (Assima et al., 2014a; Oskierski et al., 2013; Pronost et al., 2011), or the effect of pretreatment and pH-swing (Bodor et al., 2013; Julcour et al., 2015; Meyer et al., 2014; Park and Fan, 2004) as well as integrated strategies for linking target mines and industries, CO_2 emitters and potential mineral carbonation plants (Bodénan et al., 2014). Alkaline wastes such as steel slag (Capobianco et al., 2014; Kirchofer et al., 2013; Salman et al., 2014), cement kiln dust (Huntzinger et al., 2009a,b; Noack et al., 2014), coal fly ash (Mayoral et al., 2013; Montes-Hernandez et al., 2009; Wee, 2013), saline waste water (Dilmore et al., 2009), and municipal solid wastes (Um et al., 2013; Washbourne et al., 2015) are also being evaluated for their usefulness in carbonation, in addition to the role of bacterial activity in mineral carbonation, *i.e.*, carbonate biomineralization (Bundeleva et al., 2012, 2014).

---

[*] Corresponding author.
E-mail address: Faical.Larachi@gch.ulaval.ca (F. Larachi).

http://dx.doi.org/10.1016/j.ijggc.2017.06.016
Received 29 March 2017; Received in revised form 11 June 2017; Accepted 25 June 2017

Under ambient conditions, different environmental factors such as temperature, CO_2 supply, water availability, and wetting/drying cycles may take part in the formation of meta-stable or secondary carbonates such as lansfordite ($MgCO_3{\cdot}5H_2O$), nesquehonite ($Mg(HCO_3)(OH){\cdot}2H_2O$) or hydromagnesite ($4MgCO_3{\cdot}Mg(OH)_2{\cdot}4H_2O$) (Assima et al., 2014b; Entezari Zarandi et al., 2017; Harrison et al., 2015; Oskierski et al., 2013; Wilson et al., 2014; Zhao et al., 2010). In-situ formation of these carbonates sometimes has serendipitous advantages such as the ability to cement the reacting particles together to prevent air-borne transport of mineral fibres, such as chrysotile. Research conducted in our group to date showed that carbonation is sensitive to water saturation and watering frequency of the soaked mineral specimens while stability of the carbonate products is also affected by water availability and wetting/drying episodes (Assima et al., 2012; Entezari Zarandi et al., 2016, 2017). Such environmental factors and their incidence on the types of carbonates are also highlighted in many recent studies. Turvey et al. (2017) employed a portable X-ray diffraction analyzer for in-situ quantification of the passive mineral carbonation in the form of hydromagnesite, and to a lesser extent, of pyroaurite crusts in the Woodsreef Chrysotile Mine, Australia. This finding is of practical interest by noting the evolution of nesquehonite, forming erstwhile, into hydromagnesite and pyroaurite also in agreement with our earlier observations (Entezari Zarandi et al., 2017). For the case of mineral carbonation over arctic and subarctic climate zones, Ulven et al. (2017) and Beinlich and Austrheim (2012) have shown the presence of dypingite, artinite and nesquehonite, the latter evolving form lansfordite, over mine tunnel rocks in Feragen ultramafic body.

The aim of the present study is to gain knowledge on the carbonation behaviour of the different mafic to ultramafic lithologies of the Dumont nickel project at ambient temperature and wet conditions. Fig. 1a shows the location of the Dumont nickel project (DNP) in the Abitibi-Temiscamingue region in North-Western Québec (Canada). DNP is estimated to be the world's fifth largest nickel production site (Staples et al., 2013) with a target to exploit nickel sulfides, namely, pentlandite, $(Fe,Ni)_9S_8$, and heazlewoodite (Ni_3S_2), as well as nickel-iron alloys in the form of awaruite ($Ni_{2.5\text{-}3}Fe$). The Dumont sill consists of a layered mafic-ultramafic intrusion (6800 m in length with average thickness of 700 m) located in the Abitibi greenstone belt (Fig. 1b). It is composed of variably-serpentinized dunite rocks rich in lizardite with minor amounts of chrysotile, brucite, magnetite and antigorite (Duke, 1986; Sciortino et al., 2015). The sill is a lower-ultramafic zone comprising dunite and peridotite overlain by a mafic zone of gabbro, quartz gabbro and clinopyroxenite (Duke, 1986). The sill is hosted in mafic volcanics which make up the Abitibi-greenstone belt. Several faults (Fig. 1c) parallel to the strike of the intrusion have caused offsets in mineralization as well as alteration supported by structural core logging data and airborne magnetometer surveys (Sciortino et al., 2015). The ultramafic zone itself is comprised of upper and lower peridotite and dunite subzones as shown in Fig. 1d. The nickel deposit is hosted in the dunite subzone.

These four lithologies pertaining to the Dumont nickel project were studied for assessing the carbonation capacity in ambient conditions of their resulting waste rocks and processing tailings. Mineral carbonation was monitored using a differential batch carbonation cell and carbonate precipitation cells aided with an ensemble of characterization techniques before and after carbonation (X-ray diffraction and thermogravimetry analyses, Fourier transform infrared spectroscopy, optical microscopy, and quantitative evaluation of minerals by scanning electron microscopy). Stability of the neo-formed carbonate product was also assessed in terms of mineralogical evolution over time. Finally, some design recommendations are formulated to circumvent limitations inherent to the lower reactivity of waste rocks as opposed to the

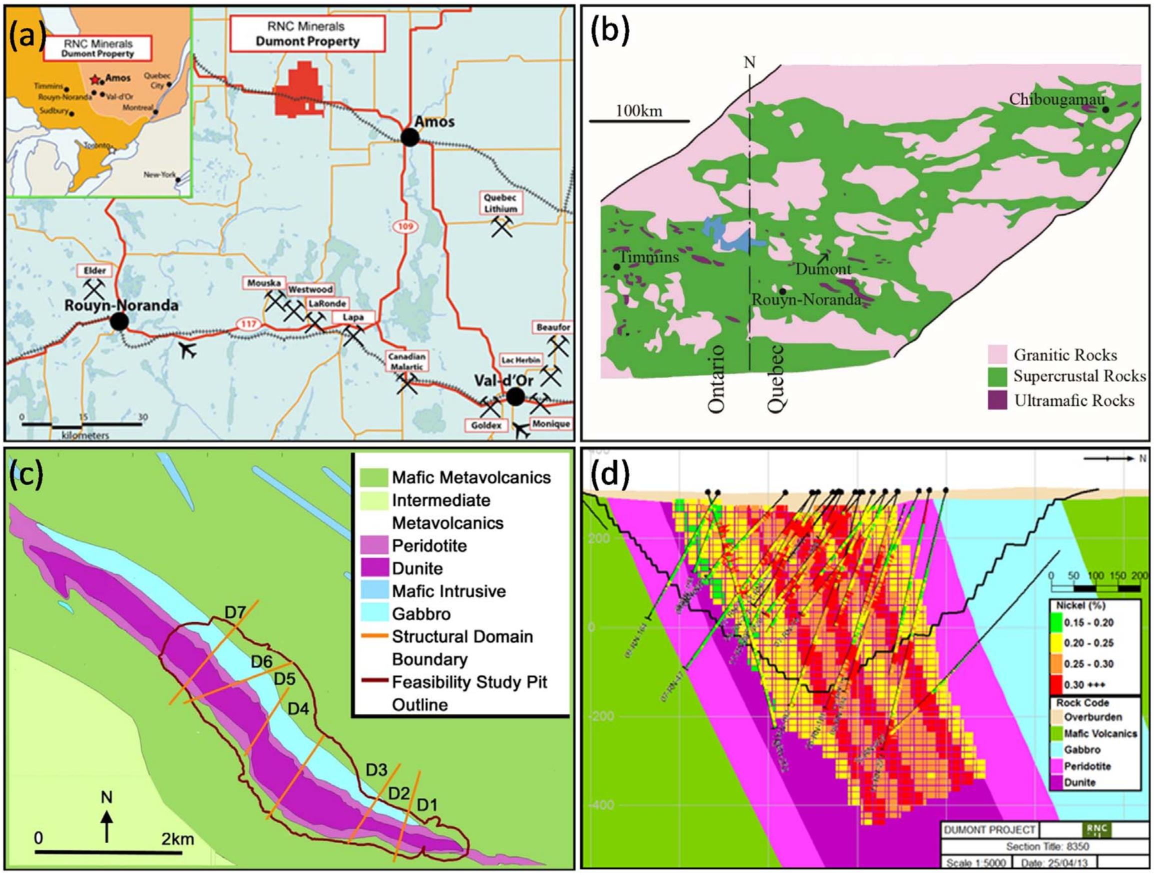


Fig. 1. Location of Dumont site (a), geologic map of the Dumont sill within the Abitibi greenstone belt (b), geologic map of the Dumont deposit (60–70° dip to NW) (c), cross-sectional view of the Dumont deposit with drill holes showing lithology down drill hole trace (d). (All maps provided by RNC minerals).