THE NEED FOR SUSTAINABLE MINING:

Characterization of Ultramafic/Mafic Minerals for Mine Reclamation in BC

ANNE AYOMIPOSI JOSEPH

2111 Lower Mall,
Vancouver,
BC, V6T 1Z4.

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Supervisors

Prof. Les Lavkulich (LWS)

Prof. Greg Dipple (EOSC)

Master of Land and Water Systems

Faculty of Land and Food Systems

University of British Columbia

Vancouver, British Columbia

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EXECUTIVE SUMMARY

The impact of anthropogenic activities such as mining necessitates the knowledge of mechanisms to reduce disturbances to land and water resources affected, contributing to sustainable approaches to mine reclamation in British Columbia (B.C.). Greenhouse gas emissions (GHG), a significant threat to climate change, have urged mining companies to diversify methods to sequester carbon to tackle these issues in B.C. Mine tailings have been useful as a feedstock in sequestering carbon, creating opportunities for mining companies to balance any emissions they may have produced during exploration activities. However, these tailings have posed dangers of acid mine drainage (AMD) and metal leaching (ML) into surrounding geoecosystems. Peer-reviewed articles were analyzed and used to assess the effect of biological activities in mine tailings. Organic amendments such as biosolids were found to have a positive impact on mine sites over long periods. Carbon pools, plant productivity, soil physiochemical properties and application rates of biosolids on mine soils were evaluated to assess the effect of biosolids. Outcomes revealed an increase in enzymatic activities, soil quality and quantity, positively impacting the biogeochemical cycle. The most significant impact is a cost-effective approach for neutralizing acidified mine soils through AMD and ML, reducing land and groundwater contamination hazards. In addition, a systematic review on the study of weathering rates of mine tailing was also conducted. A significant synthesis suggests that it is essential to conduct further research to understand the weathering sequence of minerals coupled with the addition of organic amendments to ultramafic mine tailings to promote the formation of anthroposols during carbon sequestration. This synthesis has provided the basis for studies related to mine reclamation of lands affected by acidified processes, which is pivotal to developing a sustainable geoecosystem.

1.0 INTRODUCTION

1.1 BACKGROUND

Climate change is gaining more attention globally each day as it poses great threats to human society. About fifty–one billion tons of greenhouse gas emissions (GHG) are added to the atmosphere every year. The most crucial concern worldwide is targeting net zero emissions by 2050 (Gates, 2021; Natural Resources Canada, 2021). On April 31, 2021, Canada joined the U.S. in establishing Net-Zero Producers Forum to increase the execution of the Paris Agreement on Climate Change and the target of reaching net-zero emissions by 2050. One of the oldest exploration industries on earth, mining, is recognized as having complex concerns of GHG emissions and climate change that are tied to various aspects of environmental, social, political, and technological views, most notably in the quest for energy transition metals (Lèbre et al., 2020; Malli et al., 2015). There has been an increase in projects with high carbon (C) footprints, unsustainable supply chain, and low workforce localization; hence, funding these projects has become problematic.

Approximately 419 million tons of Ultramafic/Mafic (U/M)[1] mine tailings are produced yearly from global production of metals and minerals, potentially having the capacity to sequester C, thus establishing a path for the mining industry to offset their GHG emissions (Power et al., 2020a). Mine tailings and spoil are the two major materials from mining activities (Sarkar et al., 2017). Mine spoils are materials generated from quarries, open-cast excavations, or underground mining, and mine tailings are the mixture of materials obtained after crushing, processing, and extracting the ore's valuable minerals. Mine tailings are generally viewed as waste leading to acid mine drainage (AMD) and metal leaching (ML) and causing environmental disasters such as groundwater contamination (Saria et al., 2006). At the same time, they are potential feedstock to sequester C and treat AMD and ML utilizing some specific methods (Malli et al., 2015).

Mine tailings are non-organic materials that can only host-specific vegetation types that lack available nutrients and are unsuitable for microbial habitat development and diverse plant growth. Hence, biological aspects of the tailings can be improved to allow biodiversity (Brearley, 2015). Most research has paid attention to the non-biological characteristics of mine tailings,

[1] *Ultramafic/Mafic mine tailings – Mine tailings consisting of mafic minerals with less than 10% feldspar; they include peridotite, dunite, pyroxenite, basalt, etc. (Adapted from Jain, 2014).*

however few studies effectively explored the use of microbial activities to enhance weathering rates in U/M rocks to form anthroposols[2] with soil amendments to improve climate, soil and food security (Beerling et al., 2018; Kantola et al., 2017; Reid & Naeth, 2005; Berge et al., 2012). Therefore, establishing a solid relationship between all elements in a geoecosystem, including biotic activities, will increase knowledge about the mine reclamation of U/M Soils.

The tailings are not suitable for seed germination and seedling formation, and due to their origin, during the processing and production of minerals. These characteristics of mine tailings have affected their properties (physical, chemical, and biological constraints), such as exchangeable cation imbalance (high Mg: Ca quotients) and high trace elements (Ni, Cr, & Co) (Vithanage et al., 2019). Therefore, improving the biological aspect of the mine tailings to make anthroposols that can serve as soil ecological engineers, essential for restoring the overall health of the geoecosystem (Nyenda et al., 2019).

1.2 SOILS IN GEOECOSYSTEMS

Soil is one of the most critical units in any geoecosystem[2] because it provides vital ecosystem services to the environment. Soils serve as a medium for plant growth, controls systems for nutrients and organic matter, C sequestration, soil organisms habitat, systems for water purification and an engineering medium (Faucon et al., 2017). Consequently, soil quality and health must be monitored to ensure degradation is avoided and reclamation is implemented to restore the soil landscape including, mine sites (Bouma, 2014).

As soils are formed by weathering rocks, the same processes occur in ultramafic rocks (U/M), containing minerals extracted and processed. The resultant material is broken down into more minor constituents – mine tailings (Sarkar et al., 2017). The Goldich weathering sequence, otherwise known as the Bowen reaction series, but in the reverse order (*Figure 1*), describes minerals' stability in rocks. U/M rocks are broken down into mine tailings and form soil gradually according to their relative stability to different environmental factors such as temperature, pressure, oxidizing conditions, microbes (Hayes et al., 2014).

[2] *Anthroposol – Azonal soils constructed by human activities during land reclamation after anthropogenic events such as Mining (Naeth et al., 2012).*

Geoecosystem – An ecosystem that is linked to a particular area where geological activities take place (Kostrzewski, 2016).

U/M mine tailings, a potential feedstock for C sequestration, are susceptible to AMD and ML when they undergo weathering and dissolution (Power et al., 2014). Mine tailings weathering starts with oxidation dissolution of sulphide mineral ore, especially pyrite exposed initially by mining activities (Hayes et al., 2014; Kefeni et al., 2017). Pyrite is the main mineral responsible for AMD due to oxidation with the aid of microorganisms, water and oxygen (Figure *2*) (Kefeni et al., 2017). Pyrite oxidizes under different conditions to give different reactions. *Figure 3* shows the pyrite oxidation reactions where Equation 1 shows pyrite (FeS_2) oxidation in the presence of

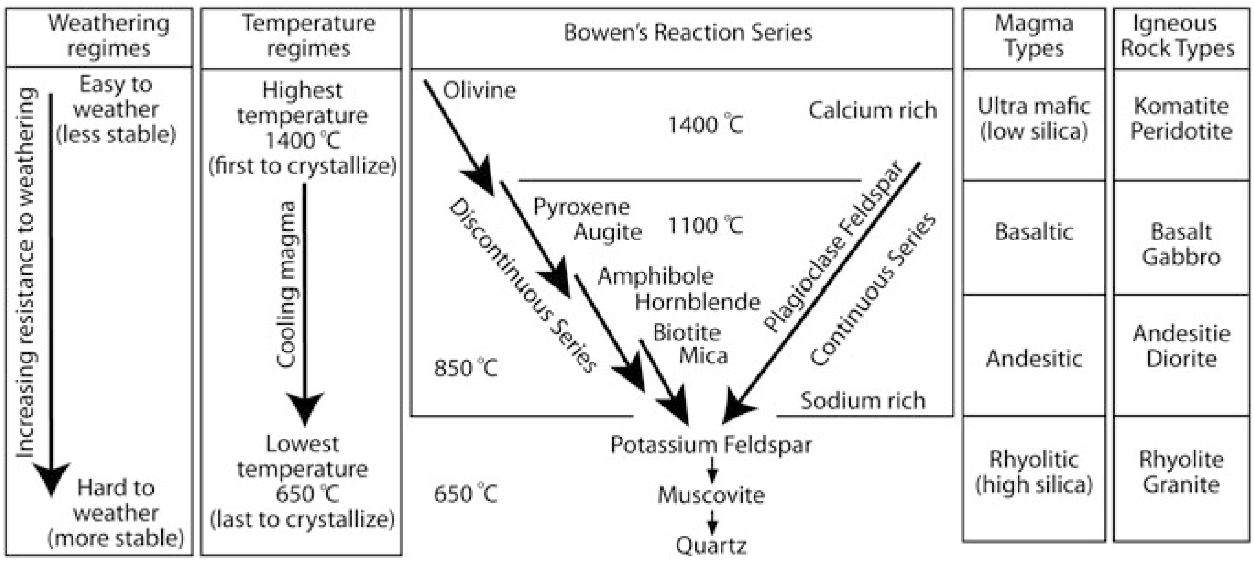

Figure 1: Bowen Reaction Series (Jain, 2014).

$$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2H_2O \quad (2)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

$$FeS_2 + 15/2O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \quad (4)$$

$$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (5)$$

$$FeS_2 + 15/4O_2 + 1/2H_2O \rightarrow Fe^{3+} + 2SO_4^{2-} + H^+ \quad (6)$$

Figure 2: Equations illustrating the chemical weathering of pyrite from 1 to 6 (Kefeni et al., 2017).

water at neutral pH; Equation 1, 2, 3 is represented by 4; Equation 5 shows the complete pyrite oxidation reaction where sulfuric oxides are released, and Equation 6 represents pyrite oxidation in the presence of low water content. When water flows through these sulfuric oxides, it results in AMD and ML.

1.3 THE ROLE OF SOIL AMENDMENTS IN U/M GEOECOSYSTEMS

Mining activities have a negative impact on the ecological resources of the land, water, and organisms. AMD, one of the effects of mining, is one of the most severe environmental problems the mining industry faces because of the severe high acidity, toxic metals, and sulphate contents (Kefeni et al., 2017; Saria et al., 2006). Hence reclamation is essential to restore the original condition of the environment through different processes and techniques to reduce these impacts (Figure 3). Reclaiming mine sites requires time and resources, which is expensive, but it is advantageous as it involves using soil amendments to stabilize the soil conditions and health at mine sites (Ioannidis & Zouboulis, 2005).

Mine soils are anthropogenically formed by adding organic matter and nutrients, resulting in changes in the soil's physical and chemical characteristics, fauna, and plants' growth (Feng et al., 2019). Reclamation activities return the degraded geoecosytem to increase land productivity and ecosystem functionality. Physical properties such as bulk density, porosity, the coarse fragment of the mine soil increases, and saturated hydraulic conductivity decrease, on the other hand, chemical properties such as pH, electrical conductivity, and metal contents increase, and soil organic carbon, C: N and total nitrogen increases. Most soil microbes, including enzymes, bacteria, fungi, and earthworms, also decrease.

Soil amendments are mixed with the appropriate amount of mine tailings, materials and water to form anthropogenic soil – soils that have been modified by human activity to stabilize the soil characteristics (Liu et al., 2018). Soil amendments can be classified as carbonates, phosphates, alkaline agents, clay and iron-containing minerals and organic matter (*Table 1*). They are applied to the soil for a specific purpose depending on the particular element/metal-bearing soil fractions, the soil's properties, and the end-use of the reclaimed soil (Rahman et al., 2016). Depending on the soil amendments used, general characteristics that will change in the reclaimed ecosystems

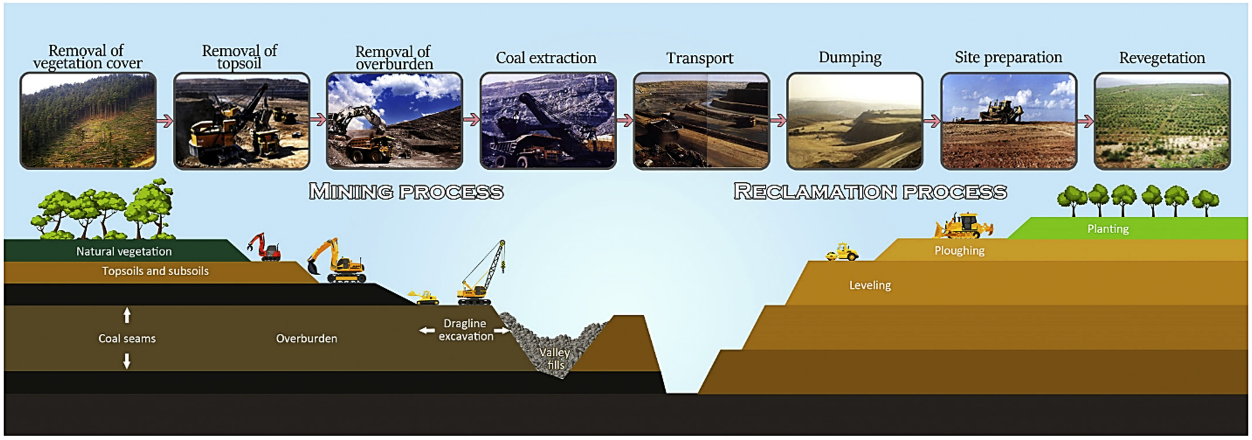

Figure 3: Resource (coal) mining and reclamation processes (Feng et al., 2019).

Table 1: Soil amendments and examples (Rahman et al., 2016).

Soil amendments	Examples
Carbonates	Lime
Phosphates	Bone meal, ammonium phosphate, apatite, and hydroxyapatite
Alkaline Agents	Fly ash and calcium hydroxide
Clay and Iron-containing minerals	Bauxite, red mud, goethite, greensand, molecular sieves
Organic matter	Chitosan, biosolids, peat, compost, manure, activated carbon, and biochar

will affect the other ecosystem subsystems related to it, such as hydrology, vegetation, landscape, and other subsystems through artificial and natural mechanisms (*Figure 4*) (Feng et al., 2019). Major physical changes include an increase in water holding capacity, structural stability and a decrease in bulk density and electrical conductivity but an increase in hydraulic conductivity and total porosity of the soil; chemical changes include an in C: N ratio, but an increase in soil organic content, pH, cation exchange capacity (CEC) of the soil; and biological characteristics increase soil microbes biodiversity to aid the cycle of nutrients in the soil.

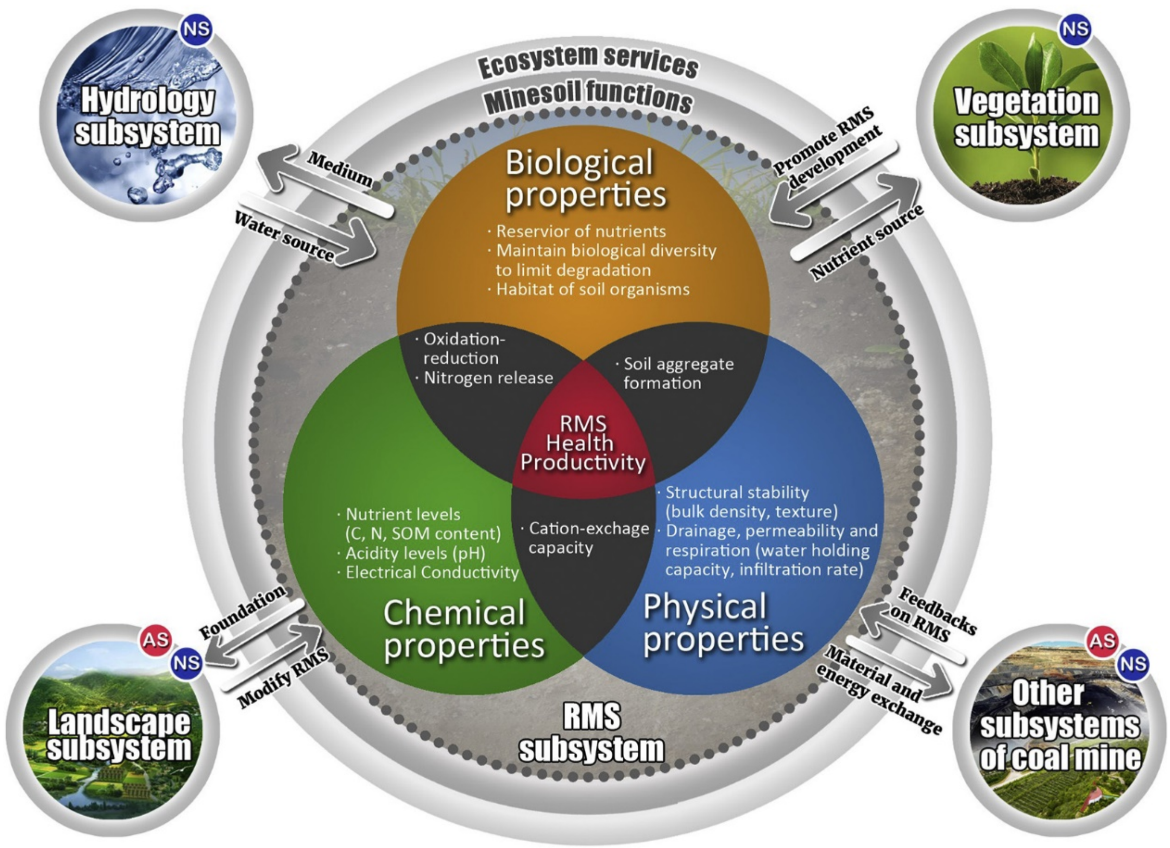

Figure 4: Interrelationship between Reclaimed Mine Soil and other subsystems in a geoecosystem (Feng et al., 2019). *AS and NS means Artificial System and Natural Systems.*

1.4 AIM AND OBJECTIVES OF THE RESEARCH

This paper evaluates mine reclamation activities by assessing the characteristics of U/M mine tailings and soil amendments to enhance the biological characteristics of mine tailings for anthroposol formation and revegetation. The objective of this research is to.

i. Study the weathering rates of U/M soils and their contribution to the biogeochemical cycle.

ii. Assess the benefits of the use of organic amendments to improve the biological activities in U/M geo ecosystems.

iii. Evaluate the Impacts of the above activities on the soil microbes in the process of revegetation.

iv. Serve as a method for further research to encourage U/M mine soils in the environment and society for reclamation purposes.

2.0 MATERIALS AND METHODOLOGY

With the aid of a systematic review and synthesis, papers and research reports were assessed on characterizing mine tailings. They recommended ways to promote the formation of anthroposols with organic amendments. The review focused on study areas centred around mine tailings in British Columbia. British Columbia is located on an active west-facing continental North America's pacific margin subjected to a subduction zone (See–Appendix). This tectonic setting resulted in numerous Alpine type and Alaskan complexes consisting of numerous ultramafic rocks. They host base metals, precious metals and gemstones; hence carrying out reclamation in this area requires innovative techniques to return the ecosystem to its original state (Voormeij et al., 2004).

3.0 RESULTS AND DISCUSSION

3.1 ELEMENTAL AND MINERALOGICAL ASSESSMENT

Depending on the mine site investigated, mine tailings releases heavy and toxic metals such as cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb) and other elements – aluminum (Al), cobalt (Co), nickel (Ni), vanadium (V) depending on their weathering its stability which may be estimated with the aid of sequential dissolution. Some of these metals can react with water and oxygen to generate acid; however, acid buffering can also occur because of the release of basic cations from the weathering of UM/M minerals releasing carbonates (calcite), hydroxides (sodium hydroxides), silicates(pyroxene) and phosphates (apatite). As suggested, this may be accomplished by sequential dissolution and other mechanisms and the release of bicarbonates and carbonic acids (Power et al., 2013, 2020b).

3.2 IMPORTANCE OF ORGANIC AMENDMENTS ON MINE TAILINGS

Improving the biological properties of weathered mine tailings will neutralize acid-generating tailing and improve vegetation and-biodiversity to restore the mine site. Organic amendments have been shown to increase soil enzyme activities (Catalase (mg g^{-1}), Urease (mg g^{-1}) and Invertase (mg g^{-1}), Microbial biomass (μg Cmic g^{-1}) (Fungal (μg cm^{-2}), Bacterial (μg cm^{-2}), Fungal/bacterial) and other soil organisms. Previous studies have also revealed that organic amendments such as biosolids neutralize acid-generating mine materials and also improve the carbon sequestrating potential of the reclaimed soil over a long period (Antonelli et al., 2018; Asemaninejad et al., 2021; Gardner et al., 2010; Hey et al., 2019; Mirjafari & Baldwin, 2016). The following section of this report explains how organic amendments may be utilized and transformed in British Columbia and more widely on all rock types – felsic, mafic/ultramafic mine tailings.

Antonelli et al. (2018) assessed biosolids' potential effects to sequester C in copper and molybdenum mine tailings for reclamation to a pasture-based ecosystem at Bethlehem Tailings Storage Facility southern interior of British Columbia, Canada. The research was carried out over 13 years (1998 – 2011) at the Teck-Highland Valley Copper (HVC) mine site to evaluate changes in C pools, plant productivity and some soil physiochemical parameters. This will require analysis for the long–term effects of biosolids, of which the short-term effects are well understood. The biosolids were applied at an increasing rate of 0, 150 and 250 dry Mg ha^{-1}. Results showed that the Total N and C concentrations increased as the application rates of biosolids increased, after 13 years, especially from 23 to 155 Mg C ha^{-1} at it was maximum at 250 Mg ha^{-1} and the C

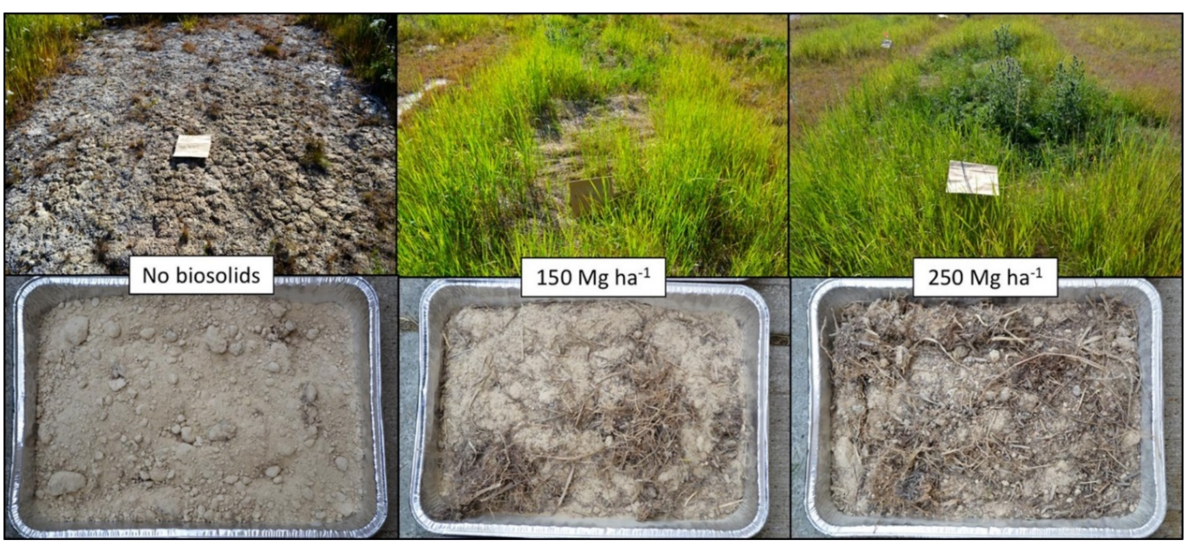

Figure 5: Biosolids-amended tailings versus unamended tailings (Antonelli et al., 2018).

sequestration potential of the tailings increased by 0.72 to 6.3 Mg C ha $^{-1}$ yr $^{-1}$. C storage efficiency of the tailings was highest at 150 Mg ha^{-1} application rate (0.74MgC/Mg of biosolids), indicating that C sequestration is efficient at lower application rates than at higher application rates. Plant population on the biosolid–amended tailings (at 150 and 250 Mg C ha^{-1}) was higher than the unamended tailings (at 0.39 Mg ha^{-1}) (Figure *5*), and the alkalinity of the unamended tailings increased with time while the biosolid–amended tailings remained neutral. The study indicated that mine tailings could sequester C and host plants when biosolids are applied over a long period.

In another study, **Gardner et al. (2010)** performed 3-year field research on the effect of biosolids and fertilizer as soil amendments for physical, chemical, and microbiological properties of copper mine tailings at Highland Valley Copper Partnership mine in south-central British Columbia, Canada. Two texturally different tailings sites were chosen in the study area. At an application rate of 50, 100, 150, 200 and 250 dry Mg ha^{-1} of biosolids, soil bulk density and penetration resistance decreased. The gravimetric water retention at Field Capacity and Wilting Point increased but remained constant in the gravimetric water holding capacity. The volumetric water holding capacity on silt loam increased compared to sandy soil, which did not change. The soil pH remained neutral, soil organic matter, total carbon and cation exchange capacity increased at increasing application rates of biosolids. There was also an increase in iron-reducing, sulphate-reducing, denitrifying microorganisms, total aerobic and total anaerobic characteristics of the tailing, indicating more biological activities in the soil. The study revealed that fertilizer amendments did not change the physical and chemical properties of the tailings. In contrast, the biosolids amendments transformed the soil quantity and fertility by enhancing the overall properties of the tailings, hence better than the fertilizer.

Hey et al. (2019) analyzed alternative and cost-effective materials in building a capillary barrier cover (CBC) for reclamation of mine sites and disturbed lands at Vale Canada Limited Copper Cliff Tailings Facility, Sudbury, Ontario Canada. Two biosolids types were considered for the research – Toronto amendments and Custom Reclamation Mix (CRM) (leaf waste, yard waste and 1:1 volumetric mix of anaerobically digested biosolids used to make a multilayer cover system). About 132 litres (seven 5-gallon buckets) of each biosolid material was examined from the stockpile to carry out numerical unsaturated flow modelling, laboratory column testing of biosolids CBCs and material characterization. Results show that the biosolids had a high saturated surface disallowing oxygen and water flux movement, revealing a low saturated hydraulic conductivity of

4.21 X 10^{-7} at e = 4.01 with an air entry value of about 400KPa. The research showed the capacity of biosolids to be a cost-effective approach to reclaiming degraded soils and alleviating acid mine drainage compared to the uncovered tailings.

Asemaninejad et al. (2021) examined the stability of a mixture of compost and lime stabilized municipal biosolids at nine (9) different rates on one (1) m thick municipal compost cover cultivated with crops at a Ni – Cu ore tailings management area in Northeastern Ontario, Canada. Application of the initial compost was made, and biogeochemical variability was observed after four to ten years resulting in the demarcation of the experimental plots into "High" rate (1600–3200 t ha^{-1} biosolids), "Medium" rate (200–800 t ha^{-1}), and "Low" rate (0–100 t ha^{-1}) remedies. Findings revealed that at an application rate of 100 t ha^{-1} biosolids and higher to the compost cover, the C: N ratio, some nutrients cations and available phosphorus drastically reduced, and potential solubility of Ni and Cu and inorganic carbon increased (Figure *6*). The research suggested that increasing the application rates of biosolids does not necessarily improve the soil quality and geochemical stability. Microbial communities were affected, and hemicellulose, cellulose, and hemicellulose decomposers were reduced at medium–and high–rate treatments, increasing denitrification activities. Hence, knowing the implications of biosolids application rates will enable the long-term efficiency of environmental management and reclamation activities in Northeastern Ontario and beyond.

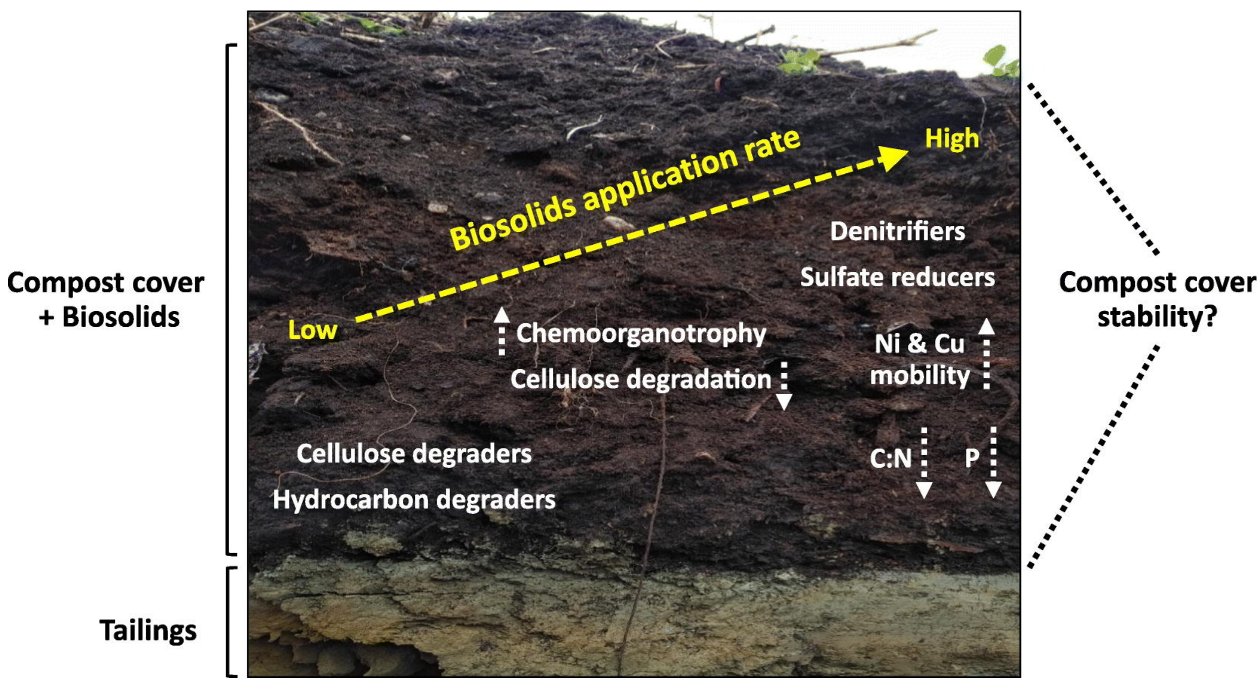

Figure 6: Changes in soil conditions during application of biosolids and compost for reclamation (Asemaninejad et al., 2021).

3.3 EFFECT OF MINE RECLAMATION ON BIOGEOCHEMICAL CYCLE

The natural pathway through which elements in the biosphere moves in a geoecosystem is essential to understand mine reclamation, effectively restoring degraded land to its fully functional state (Brusseau, 2019). This natural pathway can include the carbon, nitrogen, phosphorus, water and sulphur cycles collectively known as the biogeochemical cycles. There is no doubt that weathering of U/M mine tailings coupled with organic amendments releases elements and microbes that move within a geoecosystem. Soil microbes are significant drivers of global biogeochemical cycles and abundance, development and diversity of aboveground plant communities (Li et al., 2016). Through different soil carbon and nitrogen fixation processes, sulphur and methane metabolism by soil microbes cycles oxygen, carbon, nitrogen, phosphorous, and other essential elements, which increases soil fertility and plant growth (Tripathi et al., 2016).

Soil microbial communities are transformed during mine reclamation, and they are either slightly changed, remain constant or change completely. The succession of soil microbes has been researched to respond differently to reclamation vegetation and time (Li et al., 2016). Fungal diversity significantly changes, but bacteria and archaeal diversity found changed slightly. Fungi is more dependent on soil nutrients such as N and C, bacteria and archaea before the organic matter is added to the soil. Therefore, understanding the relationship between crucial soil microbial communities and their response to revegetation will reveal the limitations of microbial communities during reclamation successions. Power et al. (2009) utilized the understanding of the biogeochemical cycle to create biogeochemical models for CO_2 sequestration of the hydromagnesite [$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$] playas at Atlin, British Columbia, Canada. Biogeochemically generated CO_2 was found to be sequestered by microorganisms from weathering of bedrock and the precipitation of carbonate minerals. Further studies can focus on this knowledge for exploring revegetation activities and other essential elements in the biosphere.

3.4 IMPLICATIONS OF THE USE MINE SOILS IN THE SOCIETY

Table 2: Sustainability issues in tailings management (Adiansyah et al., 2015).

Environment	**Economy**	**Social**	**Government (regulation)**
Air and water pollution	Capital expenditure	Health issues	Legal Compliance
Water resources depletion	Operating expenditure	Safety issues for public (after closure)	
Ecosystem destruction	Reagent loss	Stakeholder perception	
Ecosystem alteration	Energy cost	Cultural impacts	
Land footprint	Closure cost		
Emissions			

Mine tailings management during and after exploration activities can be challenging and potentially impact the environment, economy, social and governmental regulations of the stakeholders' community (Table 2) (Adiansyah et al., 2015). However, initializing reclamation of mine tailings from the initial stage of exploration activities will minimize these impacts. The key mine tailings components – water, energy, cost, technology, and environmental impact has to be prioritized to effectively manage the tailings through principles of minimizing tailings production and increasing tailings reuse, adoption of a risk-based approach, and fulfilling crucial social, environmental and economic aspects (MCMPR & MCA, 2003).

Biologically characterizing mine tailings fulfils sustainability issues in tailings management to a great extent; therefore, adopting these mechanisms will enhance mine reclamation for the benefit of the stakeholders living near the mine sites. It is believed that U/M geoecosystem are areas where metal concentration is viewed as a distinctive geochemical background of value. This is as opposed to being a source of pollution, but plant species and water in these areas have been shown to have high levels of mobile Ni, Co and Cr harmful to the ecosystem (Kierczak et al., 2020). Improving the biotic activities on U/M soil geocosystems can be implemented for revegetation, mitigating climate change, and restoration activities in mine sites that can improve the ecosystem, economy, and social well-being community and change government legislation.

MCMPR & MCA (2003) developed a framework for managing tailings from the exploration to closure of mine site based on fundamental principles – Stewardship, Stakeholder Engagement, Risk Management, Implementation and Closure (Figure 7). The framework will go a long way in identifying and solving key sustainability issues of the reclamation of mine tailings. It provides a viable platform for implementing the environmental management practices, informing and consulting stakeholders related to risks and impacts, rehabilitation and reclamation of degraded land, and safely disposing and storing tailings(Adiansyah et al., 2015).

Figure 7: MCMPR strategic framework for tailings management (MCMPR & MCA, 2003).

4.0 CONCLUSION

Resolving climate change goes beyond regulating GHG emissions to stabilize the ozone layer. It is necessary to monitor other factors contributing to the objectives of Net-zero emissions mechanisms, such as carbon sequestration. Carbon sequestration in U/M soils is accompanied by AMD and ML challenges that various methods can resolve. Previous research has established a solid connection between U/M geoecosytem and its components, neglecting how biological activities can be improved during reclamation activities of revegetation on mine sites in B.C. Incorporating the biological characterization of mine tailings can improve the soil enzyme activities and soil microbes. In addition, these organisms and their metabolic activities can revegetate the site for reclamation, neutralize acid-generating mines, sequestrate carbon in soils, and the long term, reduce GHG emissions in the atmosphere. While implementing reclamation activities, adequate management of mine tailings is crucial by adopting a risk-based approach, reusing tailings, decreasing production, and critical social, environmental and economic aspects.

Future research

This white paper centred on a systematic review and synthesis of various mine reclamation research to understand the biological characterization of U/M soil in geoecosystems. This will also unravel the challenges of AMD and ML during carbon sequestration processes. This assessment provides a background for further research will also be a platform for other investigations in related studies.

5.0 RECOMMENDATION

Based on this research and findings for sustainable mining to achieve effective reclamation of degraded mine sites, the following recommendation is suggested.

- Consider adopting diverse, safe and ecosystem-friendly organic amendments, including biosolids, but it is necessary to know their effectiveness and applicability rates.
- Mining companies should continually embrace these mechanisms of improving mine spoils biologically rather than only the chemical concerns, as it may yield better results for mine reclamation.
- Effective mine tailings handling and management to avoid groundwater contamination and other environmental issues can be strengthened.
- Engaging and considering the concerns of the community stakeholders more frequently to improve communication from the exploration to the reclamation and closure of the mine sites.
- Policies surrounding the use of mine tailings can be encouraged through extensive research on biologically characterizing mine tailings for revegetation purposes.

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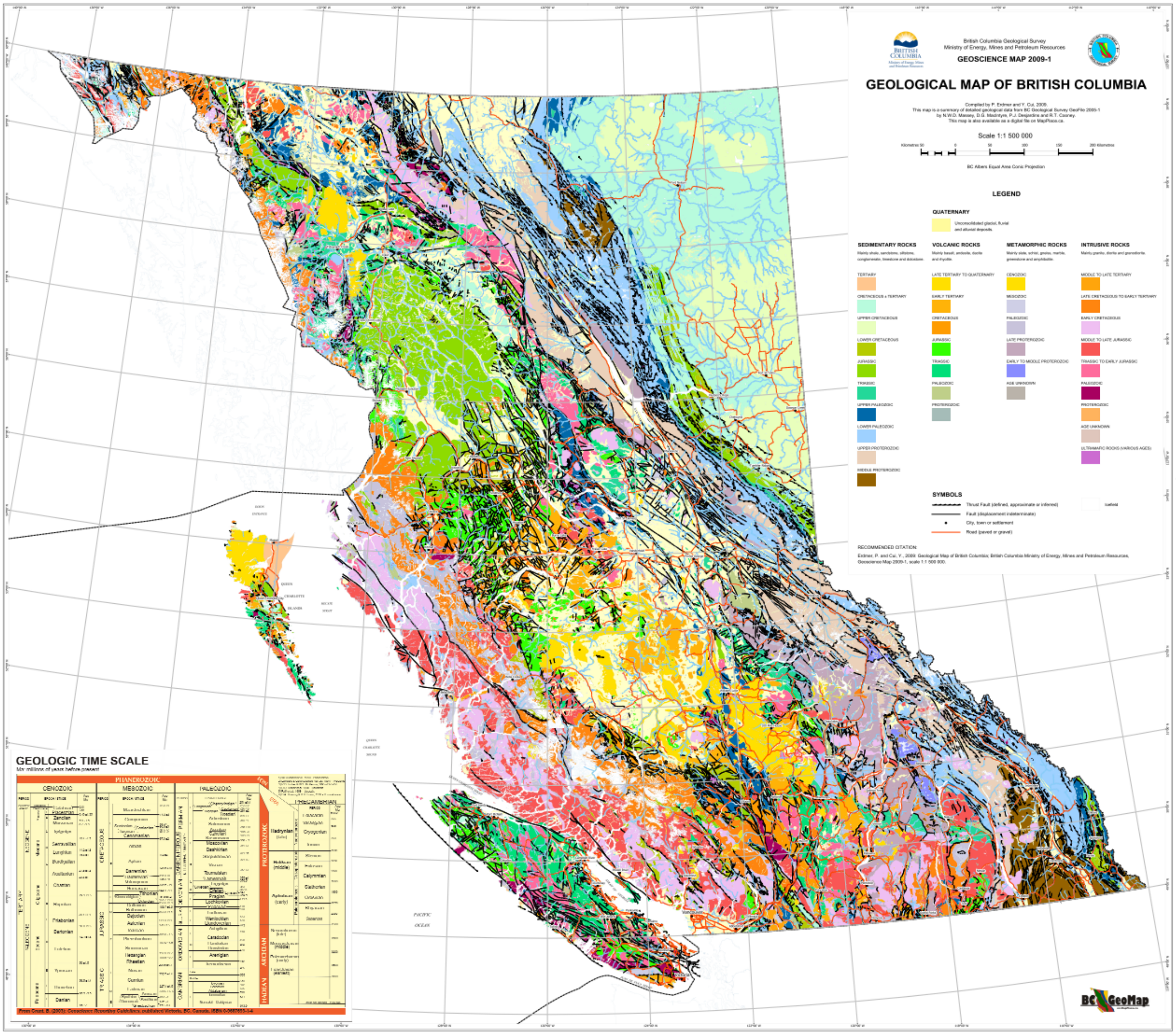
APPENDIX



Geological Map of British Columbia showing the location of Mine tailings (Erdmer & Cui, 2009).