Mine Closure 2026 – AB Fourie, G Boggs, J Heyes & M Tibbett (eds)
© 2026 Australian Centre for Geomechanics, Perth, ISSN 2208-8296
doi:10.36487/ACG_repo/2615_130

Development of a progressive closure strategy for management of potentially acid-generating materials at a coal mine in British Columbia, Canada

Michael Herrell [a,*], Dan Farmer [b]

[a] *SRK Consulting, Canada*

[b] *Telkwa Mining Limited, Canada*

Abstract

Mining has to the potential to expose rock containing acid-producing sulphide minerals, that in their natural state, are benign. When exposed to atmospheric oxygen, these minerals oxidise and produce acidity. If the mine rock does not contain sufficient neutralisation potential to offset acid production, acid rock drainage (ARD) will occur. As the pH of the drainage is depressed, oxidation rates increase, and the solubility of several mineral phases concurrently increases, leading to drainage quality characterised by elevated ion concentrations.

Once initiated, ARD is difficult to reverse. Robust geochemical characterisation studies are therefore required at the inception of new mining projects to inform mine material management and develop proactive closure strategies to minimise ARD and potentially reduce closures costs.

Geochemical characterisation of materials at the Tenas Steelmaking Coal Project (Tenas Project), located 7 km south of the village of Telkwa, British Columbia, Canada, indicates that ARD management will be required. To mitigate ARD, Telkwa Mining Limited (TML) has developed a progressive reclamation strategy that includes mine scheduling to facilitate construction of management ponds external to the open pit and within mined-out areas of the open pit. The management ponds will be used as reservoirs to submerge potentially acid-generating (PAG) rock progressively during operations to preclude oxidation of sulphide minerals. The proactive management of PAG rock during operations is designed to reduce the long-term closure liability associated with a project. This paper presents a practical case study of the use of a geochemical characterisation study as a direct input to the mine design and long-term closure strategy at the planning stage of a project.

Keywords: *mine waste management, progressive closure, geochemical characterisation*

1 Introduction

Mining of coal and metalliferous deposits can expose rock containing sulphide minerals to atmospheric oxygen. Under natural conditions, sulphide minerals such as pyrite are stable in bedrock when they are isolated from water and oxygen. Oxidation of sulphide minerals exposed in mine rock produced during mining generates acidity, and if the mine rock contains insufficient carbonate or reactive silicate minerals to neutralise acid production, acid rock drainage (ARD) can develop. ARD is characterised by low pH and elevated concentrations of sulphate and elements that can degrade receiving environment water quality (Mine Environment Neutral Drainage [MEND] 2009; International Network for Acid Prevention [INAP] 2009).

Management of ARD requires either preventing acid generation by limiting oxygen and/or water availability, or treating ARD once generated. Prevention is strongly preferable since, once initiated, ARD can persist for

* Corresponding author. Email address: mherrell@srk.com

decades to centuries and treatment costs can constitute a significant proportion of total mine closure liability. Geochemical characterisation of mine rock at the project design stage is therefore critical to informing mine material management strategies and closure design that include proactive ARD prevention and mitigation strategies.

Subaqueous disposal of potentially acid-generating (PAG) rock is a well-established strategy for limiting sulphide oxidation. Submergence beneath a water cover reduces oxygen availability, suppressing pyrite oxidation rates. The effectiveness of this approach depends on placing PAG rock under water before acid generation commences, which requires knowledge of the lag time to the onset of acid generation under site conditions.

This paper presents a case study of the Tenas Project in British Columbia, Canada, where a comprehensive geochemical characterisation program has been used as a direct input into the mine design. The characterisation established the acid-generating potential of mine rock by stratigraphic zone, quantified lag times to acid generation, and informed the design of a progressive closure strategy based on subaqueous PAG rock management.

2 Project background

The Tenas Project is located 7 km south of the village of Telkwa in north-central British Columbia, Canada (Figure 1). The Tenas deposit is situated within the northeast–southwest trending Skeena Arch, which separates Jurassic sedimentary rocks of the Bowser Basin in the north from Jurassic to Cretaceous sedimentary rocks of the Nechako Basin to the south. The coal-bearing sedimentary rock sequence of the Tenas Project is associated with the Lower Cretaceous Skeena Group, and unconformably overlies the Jurassic Hazelton volcanic group (Hazelton Group). A simplified stratigraphic column of the Tenas deposit is presented in Figure 2.

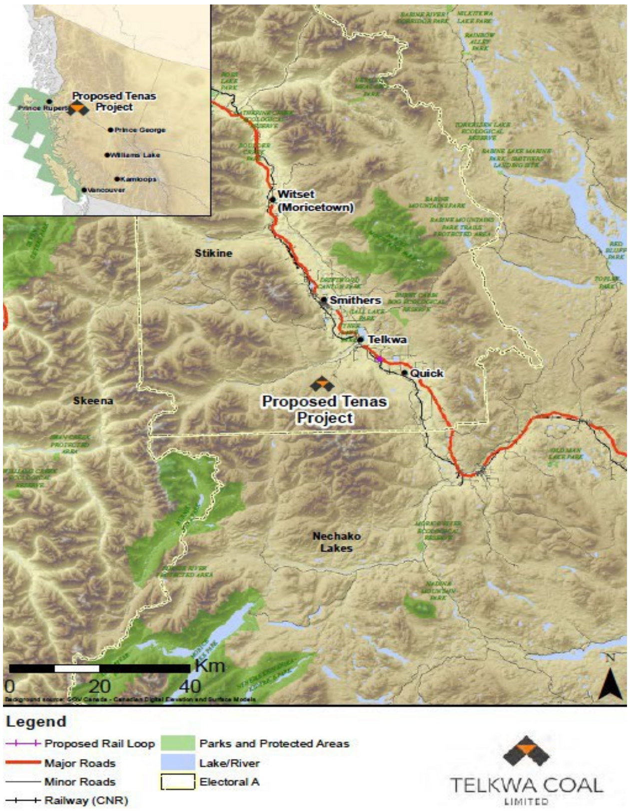
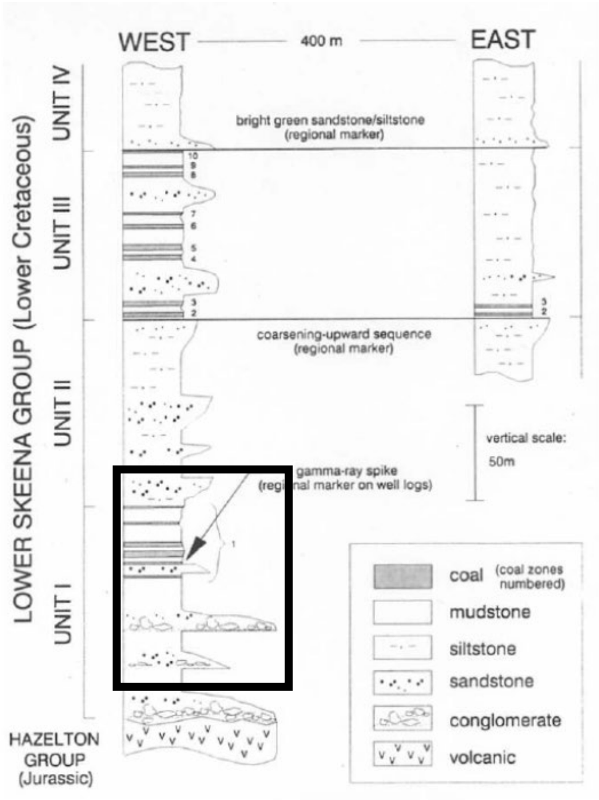


Figure 1 Location of the Tenas Project

The Lower Cretaceous Skeena Group includes marine and continental sediments interbedded with coal seams, often correlated over long lateral distances. It is subdivided into 4 units (Unit I to Unit IV). The economic coal seams in the Tenas deposit are in Coal Zone 1 of Unit I: C seam and 1 seam (upper and lower).

The proposed mining of the Tenas deposit will produce approximately 775,000–825,000 tonnes of steelmaking coal annually over a life of mine of approximately 25 years (including construction, operations and final reclamation). Coal will be extracted using open pit mining methods and will produce approximately 179 Mt of mine rock (141 Mt) and overburden (38 Mt). Geochemical testing indicates that a component of the mine rock at the Tenas Project is PAG and PAG management will be required. Coal washing will also produce coarse and fine rejects which are characterised as being PAG. Additional details on the Tenas Project geochemistry are provided in the following section.



Adapted from Telkwa Mining Ltd.

Figure 2 Simplified stratigraphic sequence of the Lower Skeena Group sedimentary sequence. Black square outlines the Tenas deposit sedimentary sequence

3 Tenas Project geochemistry

3.1 Geochemical weathering concepts

Mining of the Tenas deposit will produce pyrite (FeS_2)-bearing PAG rock. Under natural conditions, the pyrite is stable in bedrock where it is isolated from atmospheric oxygen. However, following blasting and mining of the bedrock, pyrite in the mine rock will be exposed to atmospheric oxygen prior to being placed in the management ponds. Similarly, pyrite in processed rock will be oxygen unlimited until submerged under water in the management ponds. Under these conditions, pyrite will oxidise in the presence of oxygen and water according to the following reaction:

$$FeS_{2\,(s)} + 3\tfrac{1}{2}O_{2\,(g)} + H_2O_{\,(l)} \leftrightarrow Fe^{2+}{}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2H^+{}_{(aq)} \qquad (1)$$

As seen in Reaction 1, pyrite oxidation produces sulphate, iron and acidity. The iron liberated from the sulphide can subsequently oxidise to ferric iron in neutral pH water according to the following reaction:

$$Fe^{2+}{}_{(aq)} + \tfrac{1}{4}O_{2\,(g)} + 2\tfrac{1}{2}H_2O_{\,(l)} \leftrightarrow Fe(OH)_{3\,(s)} + 2H^+{}_{(aq)} \qquad (2)$$

The above reaction also produces acidity. Mineralogical testing indicates pyrite is the main sulphide mineral at the Tenas Project, Reactions 1 and 2 are plausible mechanisms for acid production in mine rock mined from the Tenas pit or in processed rock produced from washing of run of mine coal.

Acidic conditions do not immediately form since acid production can be neutralised in the presence of carbonate minerals according to the following reactions:

$$CaCO_{3(s)} + H^{+}_{(aq)} \leftrightarrow HCO_3{}^{-}_{(aq)} + Ca^{2+}_{(aq)} \quad (3)$$

$$CaCO_{3(s)} + 2H^{+}_{(aq)} \leftrightarrow H_2CO_{3(aq)} + Ca^{2+}_{(aq)} \quad (4)$$

Some metal carbonates (e.g. siderite and ankerite) offer limited buffering potential, since during dissolution, oxidation of the metal cation produces acidity which offsets the neutralisation produced from the carbonate ion. Buffering by Reactions 3 and 4 results in a lag time to the onset of acid generation. For example, acid conditions will not occur until carbonate minerals are consumed.

Acidity can also be neutralised through dissolution of oxyhydroxide and aluminosilicate minerals; however, due to the dissolution kinetics of these minerals, they often produce insufficient neutralisation potential to produce neutral drainage (i.e. these minerals are more reactive under acidic conditions). Carbonate minerals have been identified at the Tenas Project and Reactions 3 and 4 are the predominant neutralisation reactions for the Tenas Project.

3.2 Mine material geochemical characterisation

Geochemical properties are stratigraphically (versus lithologically) constrained in coal deposits. For example, the deposition environment of the Tenas deposit includes both marine and deltaic sedimentary sequences and rocks formed in these 2 different environments will be compositionally different, even if they are of the same lithology (e.g. sandstone). The Tenas deposit's coal-bearing stratigraphy was demarcated into zones of sedimentary sequences between the mineable coal seams. The stratigraphic zones were further divided into additional zones if they had different distinct geochemical properties or grouped if geochemical properties were similar between zones identified between coal seams.

There have been 2 principal geochemical studies (Norecol Dames and Moore 1999; SRK 2024a) that included the collection and analysis of approximately 1,000 drillcore samples representative of mine rock.

Both studies followed a standard approach to geochemical characterisation (Figure 3), which consisted of bench and field-based geochemical tests.

The following analytical tests were included as part of the geochemical characterisation:

- static testing: acid–base accounting, elemental analysis and mineralogy (X-ray diffraction (XRD) and QEMSCAN)
- kinetic testing: humidity cell tests, field barrel tests, test pads and monitoring results during the bulk sample collection.

Acid-generating potential at the Tenas Project was evaluated using the neutralisation potential ratio (NPR), which is defined as the ratio of the neutralisation potential (NP) to acid potential (AP). A strong correlation (r = 0.99) exists between total sulphur measured by LECO furnace and sulphide sulphur estimated as the difference of inductively coupled plasma mass spectrometry (ICP-MS) sulphur (ICP-S) following an aqua regia leach and sulphate sulphur measured by LECO following a hydrochloric acid leach (Figure 4). Total sulphur was therefore conservatively used to estimate the maximum AP from pyrite oxidation.

Mineralogical testing results were used to estimate the effective NP using the method of Day (2009). The method is used to estimate the amount of non-neutralising iron carbonates present in the samples for known mineral stoichiometries. The proportion of total inorganic carbon (TIC) in reactive neutralising carbonates (i.e. non-iron carbonates) is subsequently estimated from the ratio of iron-corrected TIC and the analytically measured TIC, which contains both iron and non-iron carbonates. This approach shows that, on average, iron carbonates (i.e. non-reactive carbonates) account for approximately 45% of the TIC (Figure 5).

However, a strong correlation exists between the modified NP (MEND 2009) and the TIC corrected for iron carbonates. This indicates that the modified NP provides are reasonable estimate of the effective NP (Figure 6).

Since the modified NP provides a reasonable approximation of the reactive carbonate NP in the samples, an NPR of 2 can be used to characterise rock at the Tenas Project as PAG or non-PAG. The NPRs for the mine rock samples (Figure 7) indicate a large volume of the rock to be mined from the Tenas deposit is PAG (approximately 57%) and that acid-generating potential is stratigraphically constrained in zones generally separated by the coal seams. The geochemical testing results indicate that all zones contain some PAG rock; however, there are units that are predominantly PAG versus non-PAG (Figure 8). Based on an NPR of 2, the following zones were characterised as PAG and non-PAG based on their average bulk properties:

- Non-PAG: Zone 1, portions of Zone 4, overburden, construction materials and topsoil
- PAG: Zone 1a, Zone 2/3, portions of Zone 4, Zone 5, Zone 55, Zone 6, processed rock, processed coal and run of mine coal.

A key learning from the geochemical characterisation studies is the stratigraphic control on acid-generating potential at the Tenas Project make it an ideal candidate for non-PAG and PAG rock segregation. This attribute was considered in the development of the mine rock management plan for the Tenas Project. However, as noted above, all stratigraphic units contain a component of PAG rock and operational criteria for identifying PAG and non-PAG rock were also established as part of the mine material management plan (SRK 2024b).

The timing to the onset of acid-generating conditions is a key component of the PAG management strategy at the Tenas Project. Laboratory-based humidity cell tests were initially used to estimate the timing to the onset of acidic conditions. Based on the bulk static properties of each of the zones, a minimum lag time of 4 years was estimated to the onset of acidic conditions (SRK 2024a). This was confirmed through larger-scale barrel tests constructed at the Tenas Project site. These barrels, containing 150–200 kg of −¼” rock did not produce acidic drainage until 4 years of testing had elapsed. The reader is referred to SRK (2024a) for additional details on the acidic lag time estimates and field barrel testing program.

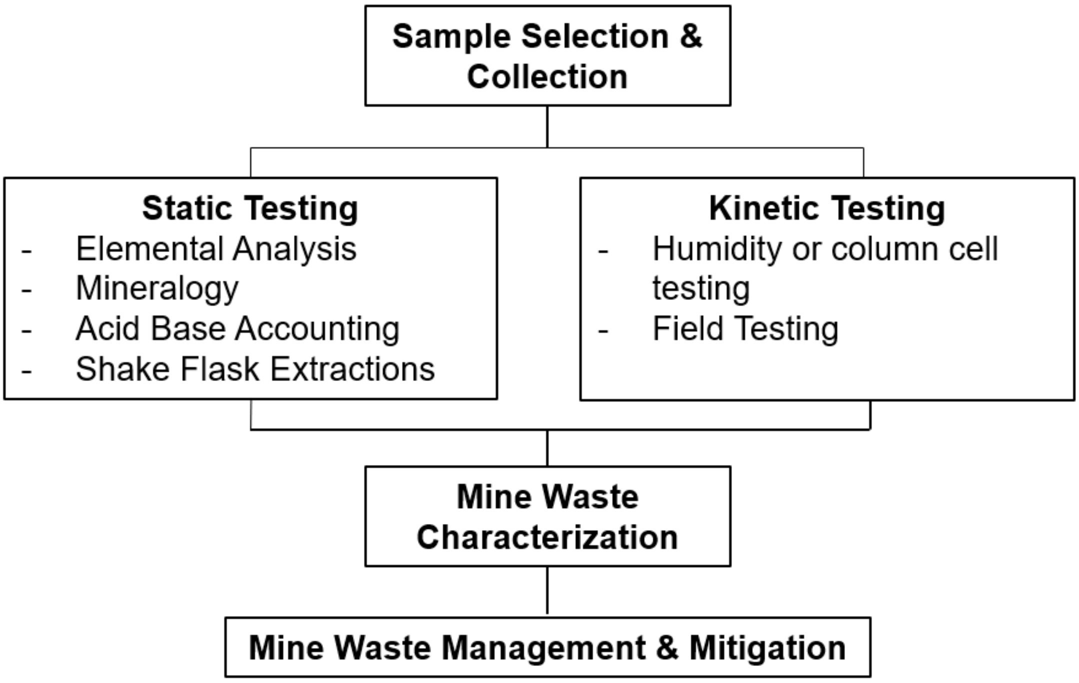


Figure 3 Generalised approach to geochemical characterisation

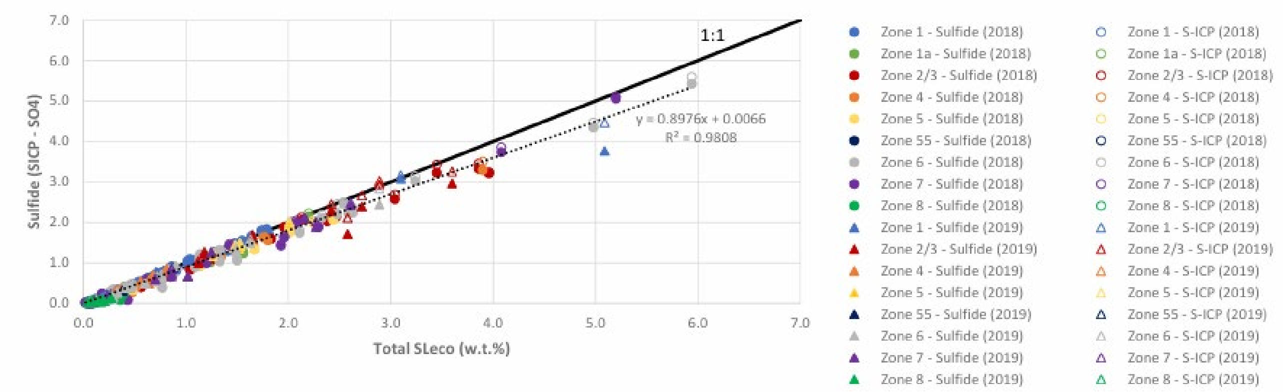


Figure 4 Total sulphur versus sulphide sulphur

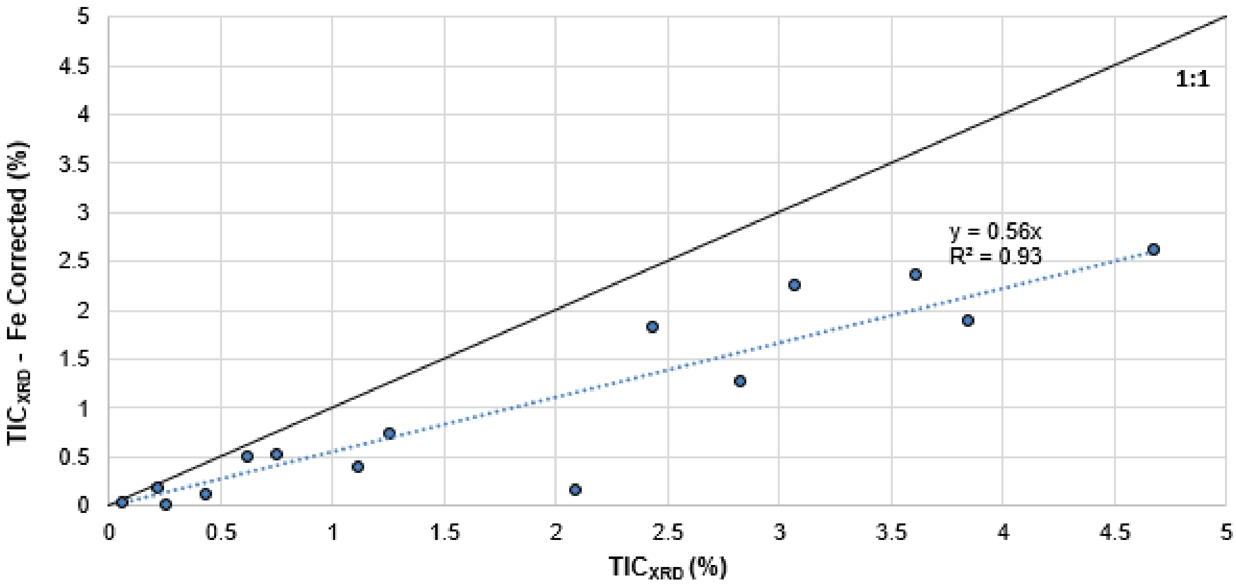


Figure 5 Total inorganic carbon versus iron-corrected total inorganic carbon

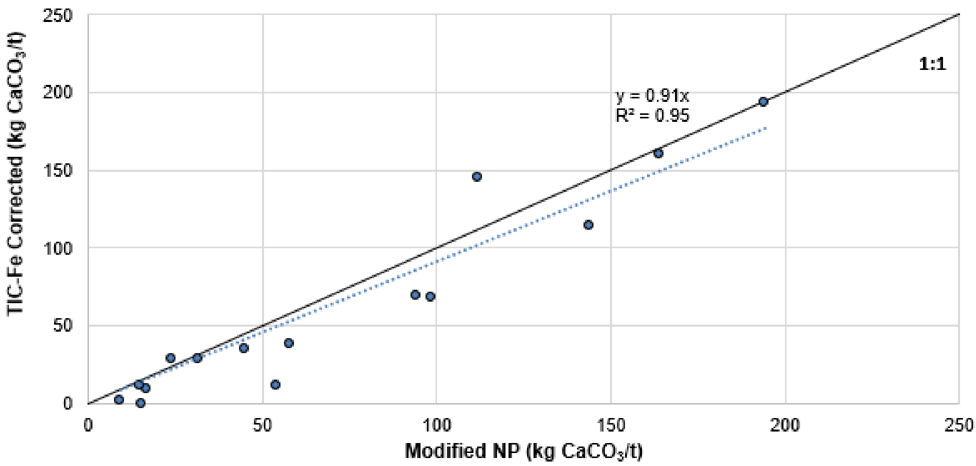
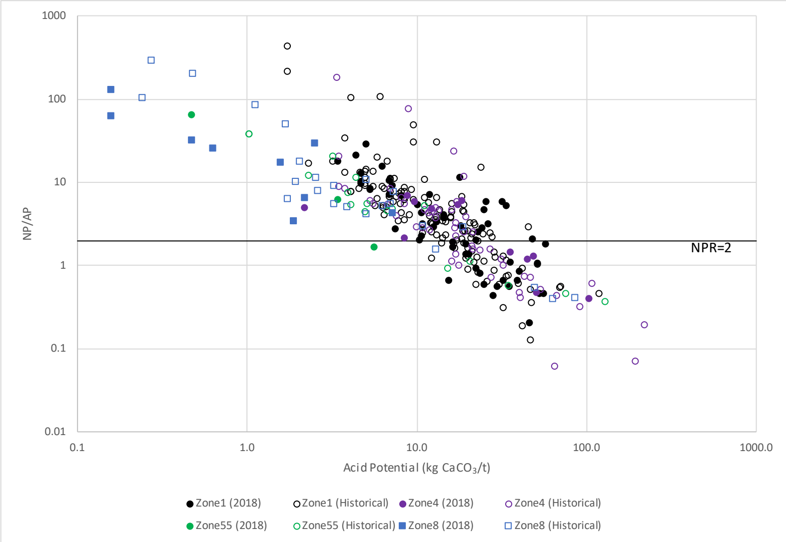
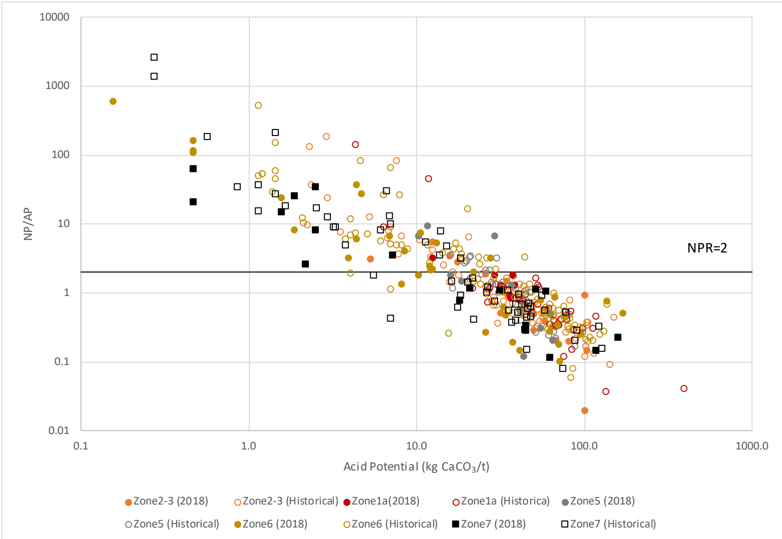


Figure 6 Modified neutralisation potential versus iron-corrected total inorganic carbon



(a)



(b)

Figure 7 Neutralisation potential ratio versus total sulphur (expressed as acid potential) by stratigraphic zones; (a) non-potentially acid-generating zones; b) potentially acid-generating zones

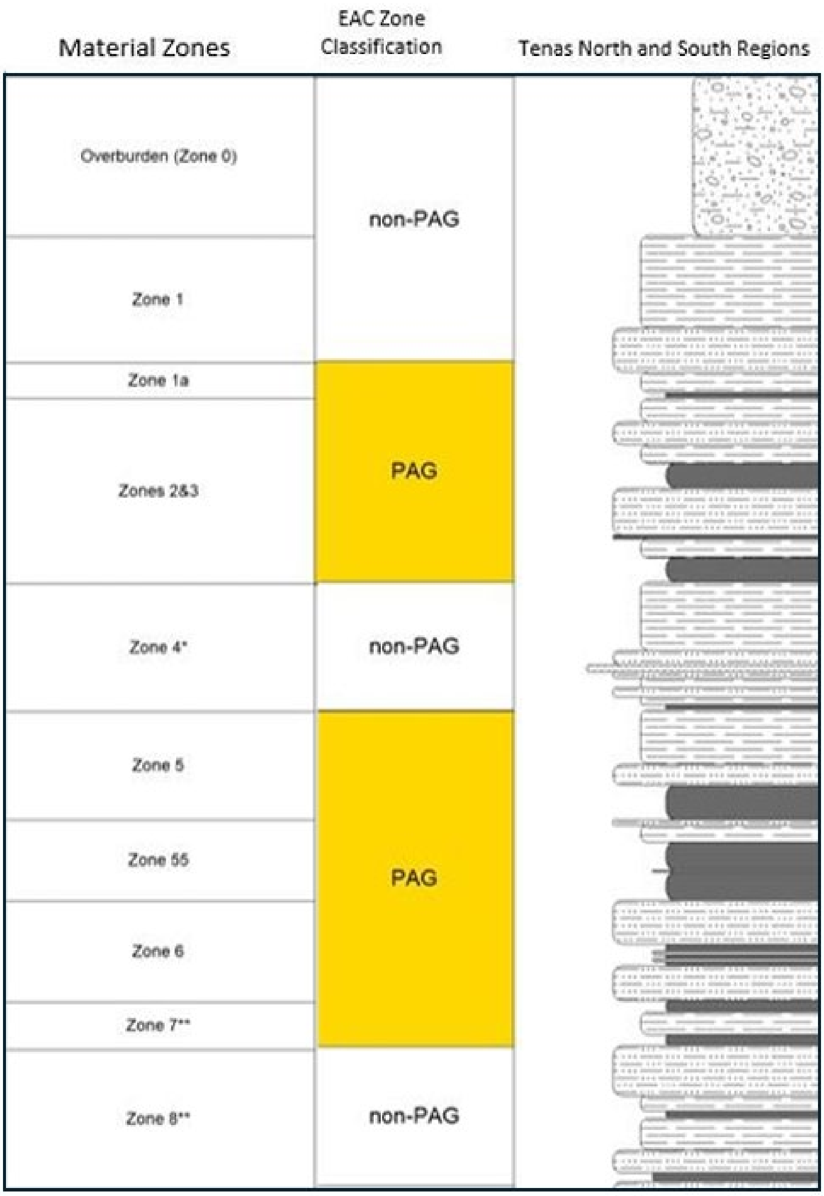


Figure 8 Tenas deposit stratigraphic zones

4 Mine material management plan

The geochemical testing results were used to model the quantity of PAG versus non-PAG rock to be mined from the Tenas deposit. Using an NPR of 2, it was estimated that approximately 57% of the mine rock was PAG and would require management. Blending was considered but this would require an additional source of non-PAG material and additional processing (e.g. crushing) to achieve an effective blend. This approach was not considered economically practicable and the mine plan for the Tenas Project was modified to include construction of dedicated PAG rock storage facilities (management ponds) to proactively mitigate PAG rock during operations.

In advance of, and during mining, TML proposes to progressively construct the following 3 management ponds (Figure 9): North Management Pond (NMP), West Management Pond (WMP) and East Management Pond (EMP). The purpose of the ponds is to store PAG and processed rock permanently in saturated conditions to minimise sulphide oxidation, limiting the occurrence of acidic drainage. The NMP will be constructed first as a ring-dyke dam during the pre-mining stage of the project. The NMP is external to the open pit and will be used to store PAG rock that is produced during the first 2 years of mining. The EMP will also be constructed external to the open pit and will consist of a dam along the northern extents of the facility, separating it from the NMP. The western limit of the EMP will be demarcated by a division dam separating the EMP from the WMP. The WMP will consist of a dam along the northern and western extents of the facility adjacent to the EMP (Figure 9). The management ponds will be lined to reduce seepage from the ponds.

PAG and processed rock will be placed in the management ponds while run of mine coal is processed into processed rock (rejects) and processed coal, with processed coal being shipped offsite to market prior to producing acidic drainage. In each of the management ponds, PAG rock will be progressively placed in lifts and then flooded so that exposure of PAG rock to atmospheric oxygen is minimised. PAG rock will be placed in the management ponds and submerged with a minimum of 0.5 m of water. The management ponds will be maintained with a 0.5 m water cover during active use and under at least 2 m of water once the maximum management pond PAG rock storage capacity has been reached.

Once the ponds have reached the maximum PAG rock storage capacity, TML will place a 1−2 m layer of non-PAG rock on top of the submerged PAG rock below the active water level of the management pond, followed by approximately 1 m overburden layer to create a dry landform above water, followed by approximately a 30 cm layer of reclamation materials (surface soils) to reduce evaporative losses from the water cover above the saturated PAG rock.

As noted above, a key component of the PAG management strategy at the Tenas Project is ensuring PAG rock is placed and inundated with water in the management ponds prior to acidic conditions forming. Depletion calculations (SRK 2024a) indicated that the minimum lag time to the onset of acidic conditions was approximately 4 years based on the bulk geochemical properties of the stratigraphic zones, which were confirmed through field barrel testing results. Based on the lag estimates and observed drainage conditions in the field barrels, the PAG management plan was designed so that mine rock would be placed and inundated in the management ponds on average within 6 months of placement with a maximum targeted exposure time of 12 months.

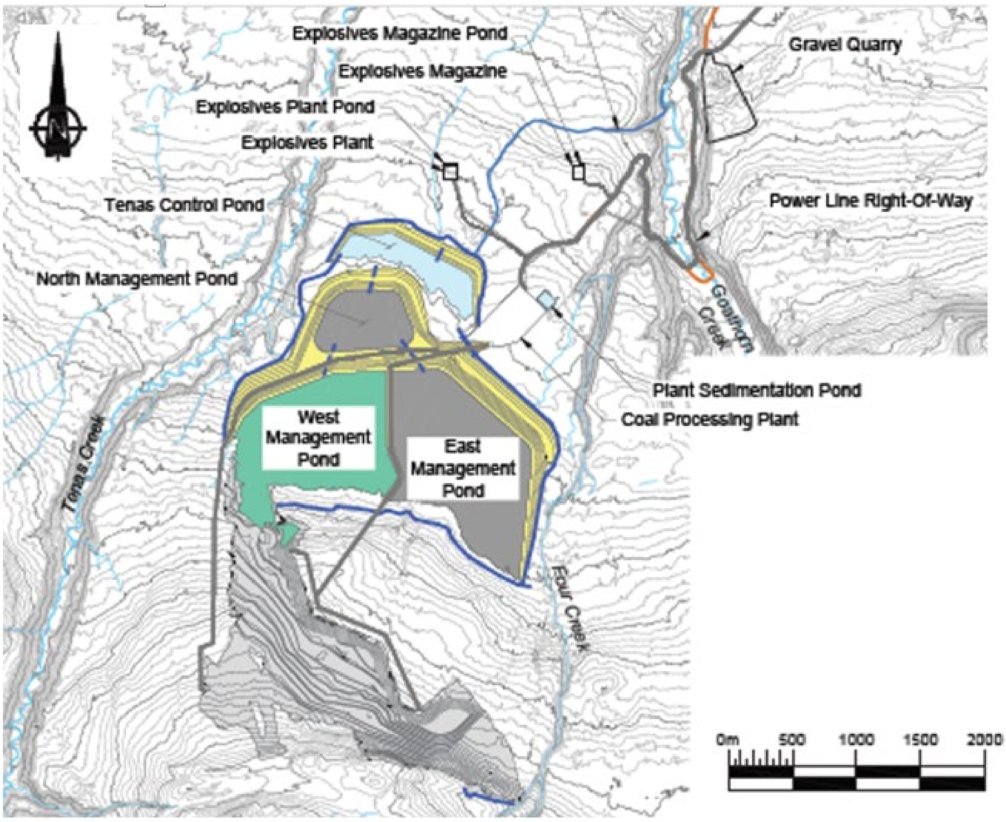


Figure 9 Tenas Project proposed site infrastructure

5 Conclusions

The Tenas Project provides a case study of use of geochemical characterisation results as a direct input into mine planning. Completion of a robust geochemical characterisation study at the scoping stage of the Tenas Project allowed a detailed understanding of the geochemical risks that would be encountered during operations of the Tenas Project and facilitated mine plan adjustments to proactively mitigate the Tenas Project's ARD risk during operations. The mine planning approach used at the Tenas Project reduced the environmental risk for the project and minimises the risk of having to implement costly strategies (e.g. water treatment) to retroactively mitigate ARD.

Acknowledgement

The authors would like to thank Telkwa Mining Limited for allowing them to use their data to support this paper and the SRK project team that has provided support to this project.

References

Day, S 2009, 'Estimation of Calcium and Magnesium Carbonate Neutralization Potential for Refined Acid-Base Accounting Using Electron Microprobe and X-Ray Diffraction', *Proceedings of the 8th International Conference on Acid Rock Drainage (ICARD) and Securing the Future: Mining, Metals & the Environment in a Sustainable Society 2009*, Swedish Association Of Mines, Minerals and Metal Producers, Stockholm, vol. 3.

INAP (International Network for Acid Prevention) 2009, *Global Acid Rock Drainage Guide,* www.gardguide.com

Mine Environment Neutral Drainage (MEND) 2009, *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials*, Ottawa.

Norecol Dames and Moore 1999, *Assessment of ARD Potential and Water Quality Predictions: Telkwa Coal Project*, Luscar Coal Ltd.

SRK Consulting 2024a, *Telkwa Coal – Tenas Project Geochemical Characterization Update*, Vancouver

SRK Consulting 2024b, *Metal Leaching/Acid Rock Drainage Management Plan*, Vancouver.