The application and use of petrography in the assessment of potential aggregate sources at mine projects

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INTRODUCTION

Most standards that are written for assessment and qualification of materials that are intended for use as concrete aggregates have implicitly been designed for aggregate supplies in urban regions. As such, the standards that are commonly used, e.g. American Society for Testing and Materials (ASTM), Canadian Standards Association (CSA), American Concrete Institute (ACI), British Standards (BS), and European Standards (or Norms) (EN), have all developed to achieve fairly rigourous and conservative requirements. In the construction materials industries that operate within various jurisdictions, countries and regions, these standards are followed to varying degrees of rigour in order to prequalify, qualify and certify aggregate products and products made using these aggregates to ensure that they are fit for the intended purpose(s). For commercial aggregate supplies, undertaking the testing programs that are required is a routine part of the business, particularly when Certification and/or Quality Control testing records are necessary. In contrast with commercial aggregate supplies, the materials that are used – or proposed for use – as concrete aggregates on remote projects may fall short of the quality levels that are routinely achieved for long term commercial aggregate supplies.

Application of these qualification standards to materials in remote areas – where geologic materials that are available may provide only a limited selection – may identify that some materials do not satisfy "typical" standards. Examples of such projects include energy sector projects, transportation infrastructure work, ports and mining projects, all of which often are faced with the need to utilize locally-available materials. In the case of mining projects, many mines inevitably make use of geological materials that incorporate metallic minerals. The relative abundance, mode of occurrence of various metallic mineral species can be difficult to assess using the standards that are applied to most commercial aggregate supplies.

In this extended abstract, we examine aggregate evaluation work done on mining projects. Cases of mining projects that illustrate these challenges are described, along with commentary on the considerations and approaches that were used to complete the qualification and assessment of certain of the sources that were evaluated.

MINE #1, ASIA

A major minesite required significant supplies of concrete aggregates to enable construction of a new phase of the mine, as it transitioned from an open pit to an underground model. The site is remote and the nearest settlements are 50 and 80 kms distant; these communities are small villages with small populations. The area is rural, with sparse population, much of it nomadic-agricultural in nature. Local/regional concrete suppliers do not exist within the area of this mine. On the order of 800,000 tonnes of fine and coarse aggregate was required for the projected concrete construction needs. Previous concrete work at the mine made use of a small on-site quarry for coarse aggregate and a local riverbed as a source of fine aggregate. Several grades and types of concrete were required for the new phase of development, including structural concrete and shotcrete. Target compressive strengths for the new project were anticipated to be in the 40 to 50 MPa range.

As a result of the first phase of mining by the open pit method, enormous volumes of waste rock were available on the site (Figure 1a). In addition, excavation of a number of mining shafts had similarly produced excavation spoils that were available and stored on the minesite (Figure 1b). Mining staff directed the focus of the investigation for concrete aggregates to the waste rock piles and excavation rock. The use of these materials would benefit the operation in that the rock was available and already excavated, required only on-site transport, and could potentially save the mine significant costs over sourcing materials from offsite locations. Thus these materials were included in the overall concrete aggregate investigation and studies.

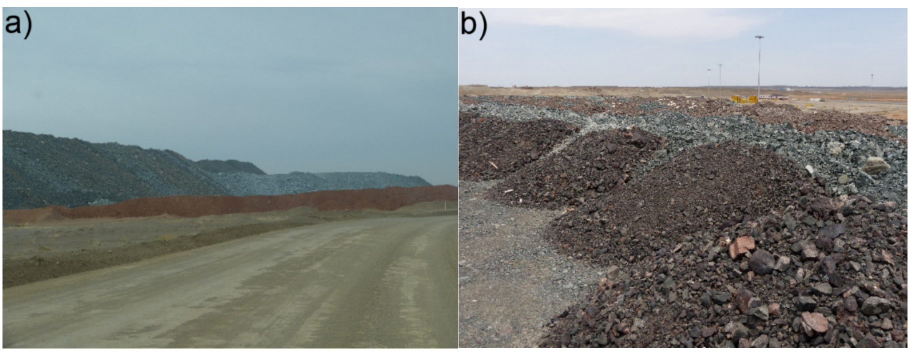

Figure 1: (a) Waste rock piles and (b) excavated rock piles.

The waste and excavated rock materials were reviewed for general characteristics, geological composition and a preliminary assessment of engineering properties, strength, weathering and projected durability. The rock were found to generally comprise volcanic and metamorphic rock types, and represented a significant range of mineralogy, rock species, alteration and weathering. By contrast, the rock exposed in the former quarry site (Figure 2) was generally a granitic rock with minor variability.

Figure 2: (a) Quarry face and (b) processed quarried coarse aggregate.

The fine aggregate sources that were proposed included manufactured fines produced by crushing of the waste rock or excavated rock; and natural river sand from a variety of local/regional sources (Figure 3).

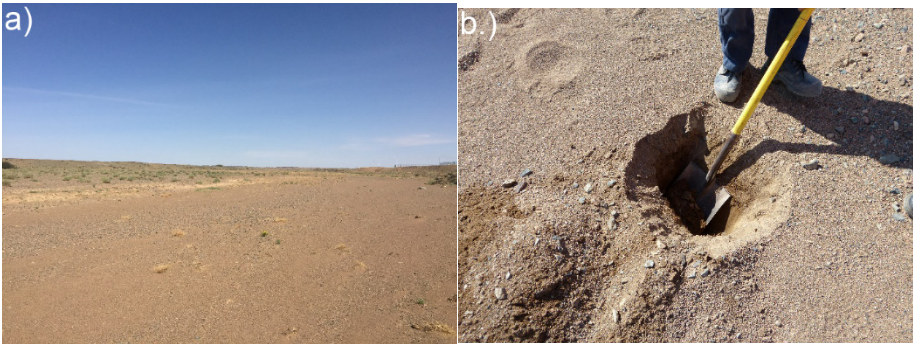

Figure 3: (a) Local river bed sand source and (b) sampling river bed.

Evaluation of the various potential aggregate supplies began with a site visit to review and examine the different materials, and obtain samples for detailed testing.

Since the mine is a metals mine, it was not surprising to determine that the waste and excavated rock supplies were characterized by the presence of metallic minerals, dominantly oxides and sulphides. The concern was whether any of the rock contained potentially deleterious forms of these minerals, such as marcasite, pyrrhotite or framboidal pyrite, due to the possibility of these minerals producing some form of internal sulphate attack due to alteration of the minerals. Unfortunately, since facilities were not available either on site, or in country, to enable the detailed testing that was necessary, a few tonnes of the materials were shipped to Canada for the testwork.

Testing Program

"Standard" characterization tests were conducted on the samples of waste rock, excavation rock, quarried rock and various natural sands. In total, four samples of waste and excavation rock, one sample of quarry rock, and three samples of sand were tested. While the physical durability tests gave results that were generally in conformance with typical specifications for concrete aggregates, the petrographic examinations and associated work provided a range of results (Table 1).

Table 1: Classification of rock types.

Sample	#	Geological Composition
Quarry site	1	Granite, minor fine-grained dike rock
Waste rock	1	Volcanic, metasandstone, calc-silicate, greywacke, quartzite, metagranite, metasiltstone/metaclaystone, argillite, mineralized vein rock, Petrographic Number 172
	2	Metasandstone, argillite, volcanics, some mineralized rock
Excava-tion rock	1	Volcanic rock, vein rock, mineralized rock, Petrographic Number 121
	2	Altered volcanic rock, altered metamorphic rock, some mineralized
Sand source	1	Natural river sand
	2	Natural river sand

The geological composition of the rock materials from both the waste and the excavation stockpiles was variable and complex. A series of volcanic rocks and metasedimentary rocks dominated most of the mine rocks. A selection of photographs illustrate some of these rock types (Figure 5).

Concerns with respect to the suitability of the waste rock materials for use as concrete related primarily to the chemical stability of the rock, since petrographic work had (1) identified a potential risk for AAR and (2) determined that the rock contained various metallic minerals, thought to consist of pyrite, chalcopyrite and thought to possibly also include potentially problematic species such as marcasite and pyrrhotite.

Alkali-Aggregate Reactivity Potential

Since decisions were required within weeks of initiation of the assessment work, it was required that evaluation of the alkali-aggregate reactivity (AAR) potential as well as the potential reactivity of metallic sulphides be developed. To address these concerns, (1) accelerated mortar bar tests (AMBT) per CSA A23.2-25A (ASTM C1260) were conducted (Table 2), (2) thin-section mounts of selected specimens were prepared for study using the polarizing microscope, and (3) mortar weathering tests were conducted.

Figure 5: (a) Sample of waste rock crushed to 25 mm: volcanics and metasedimentary rocks dominate the lithology, (b) thin-section of altered volcanic rock viewed in cross-polarized light, and thin-section of volcanic porphyry viewed in (c) cross-polarized, and (d) in reflected light, same view as previous (5x objective). Most of the metallic minerals are magnetite, hematite and ilmenite.

Table 2: AMBT results.

Source	Material	14 d expansion (%)
Quarry	KT1	0.157
	Sand 1	0.214
	Sand 2	0.229
Waste rock	Shaft 1	0.424
	Shaft 2	0.487
	Pit 1	0.505
Natural river sand	1	0.398
	2	0.281

In brief, the AMBT results showed that much of the minesite waste rock would be classified as “potentially reactive”, while the granitic rock of the quarry site had lower expansions. Furthermore, based on previous qualification testing conducted during mine startup, the granitic rock had been shown to be non-reactive. The locally-available sands all exceeded typical specification limits for AAR expansion.

The mine operations team was concerned about the long-term durability of the concrete after being apprised of these results. Upon completion of the AMBT tests, a series of concrete prism tests (CPTs) were initiated; some of these incorporated supplementary cementitious materials (SCMs) to evaluate assumed excessive expansions. However, the engineering/construction team required input and a source of concrete aggregate well in advance of the minimum one-year time frame that is associated with the CPT. For this reason, the decision was taken to adopt a conservative approach for aggregate materials sourcing for use in the concrete mixes.

One concept that was evaluated was to consider the incorporation of various levels of SCMs with the materials identified as potentially reactive to determine whether a sufficient reduction in expansion could be achieved. However, since the operations team required input within months, it was not feasible to rely on the development of data from mitigated concrete prism tests, since such a program of test would require two years to develop test information.

Sulphide Reaction

In addition to the concerns about potential AAR of some of the available aggregate sources, there were also concerns regarding the potential for sulphide mineral degradation in the concrete. This was because it was recognized that many of the site rock formations were likely to contain sulphide minerals, potentially including unstable and reactive species such as marcasite, pyrite and/or pyrrhotite. In order to assess whether such a potential existed within the varied groups of rocks that were available, a program of testing and analysis was initiated.

The focus for this portion of the assessment was two-fold: thin-section petrography and chemical analyses. The hope was to be able to determine definitively whether reactive sulphide species could be detected in the rocks, and if so, in what proportions. Chemical analyses were relied upon primarily to support/augment the petrographic work. Examination of polished thin-section mounts in polarized and reflected light enabled the characterization of the rocks including the metallic minerals (Figure 6).

On the basis of detailed petrographic examinations of numerous rock specimens, supplemented by chemical analyses, it was determined that the various rock sources did not contain reactive sulphides. A schematic depicting the parallel lines of investigation is given in Figure 7. Although the sulphide reaction potential was shown to not be a problem, the overshadowing issue was the AAR potential of the waste rock.

One issue with the evaluation of the waste rock was that there was no standard test method available that could be used to determine whether the rock might have the potential to produce a sulphide-induced internal sulphate attack response. A "weathering test" method was devised by the materials engineering team. It consisted of crushing of the subject materials to a sand grading (as used in the Accelerated Mortar bar test for AAR), preparation of mortar mixes, and producing sets of small slabs about 10 cm x 10 cm x 1.5 cm deep, and subjecting them to a series of weathering

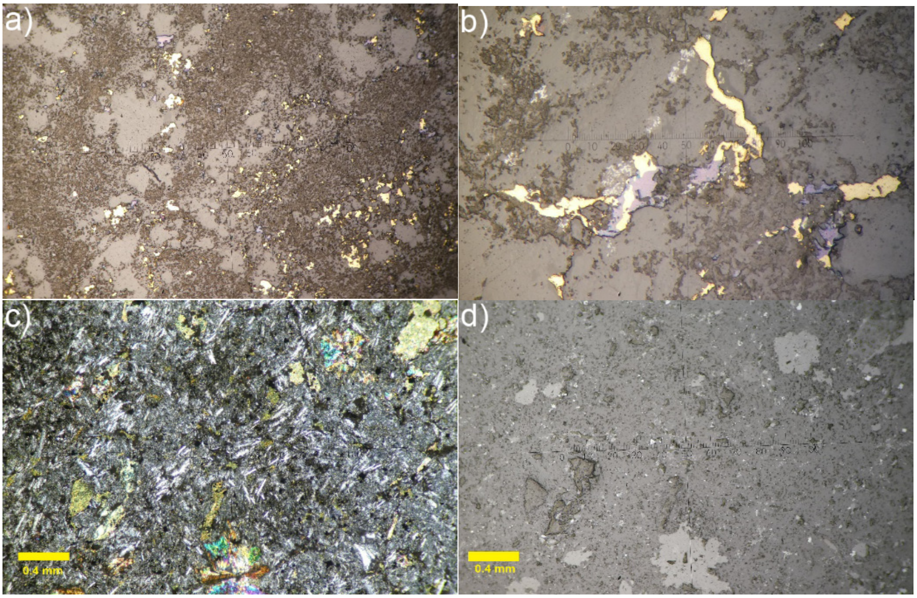

Figure 6: Thin-section views in reflected light (a) showing array of metallic minerals, 5x objective, and (b) with 20x objective, where pale yellow = pyrite; grey = bornite. Volcanic rock exhibiting some alteration under (c) crossed-polars, and same area under (d) reflected light, 5x objective. Metallic minerals are dominantly magnetite/ilmenite. No sulphides identified.

conditions, ranging from freezing/thawing, wetting/drying, heating/cooling, with intermittent moist room conditioning between some steps. These tests were run over the course of several weeks; the output data was visual assessment.

Preliminary AAR testing – with various mitigative designs – showed the material to be classified as "potentially reactive" despite the use of up to 35% fly ash replacing cement. Fortunately, the mine's operations team elected to reject the material based on multiple uncertainties regarding its projected performance.

Several months after the start of construction – in which other sources of material were used for concrete aggregates – the concrete prism tests achieved twelve month expansions that were between 0.1 and 0.14%, indicating that the material was in fact quite reactive. This was attributed to glassy phases in some of the volcanic rocks, and strained quartz in some of the metasedimentary rocks.

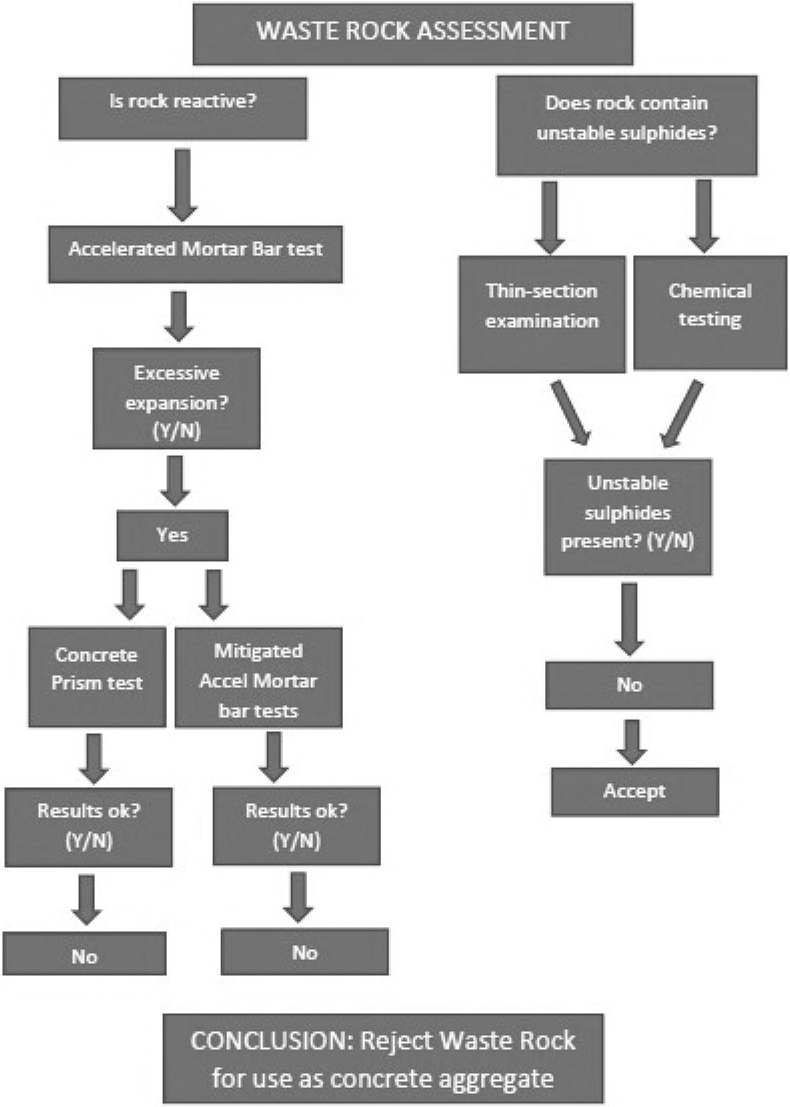

Figure 7: Generalized process flow of evaluation of mine waste rock suitability

MINE #2 – MIDDLE EAST

The second case involved a new mining project development in the Middle East where initial site preparation construction was already taking place, but significant concrete works had not yet begun. Thus, the task was to identify a suitable source of aggregates that would be appropriate for manufacture of concrete. It was planned that concreting would be started within six months of the initiation of potential aggregate resource evaluation.

The preliminary resourcing studies had identified two potential quarry sites. A series of drillholes were put down in each of the sites, enabling detailed logging of the rock and sampling for testing of the rock. Composite samples from each site were submitted for testing that include physical-mechanical durability testing and petrographic-chemical testing, to develop sufficient information that would indicate the relative suitability of either source for production of concrete aggregate. The intent was to be able to select the most appropriate site for development of a single aggregate supply for the project.

The regional geology comprised a series of volcanic formations; both sites were located in volcanic rocks, but with differing characteristics. The "Site 4" rock was a porphyritic basaltic andesite, while the "Site 7" rock was a vesicular trachyandesite (Figure 8). Both rock samples were subjected to a program of physical testing, with results in Table 3.

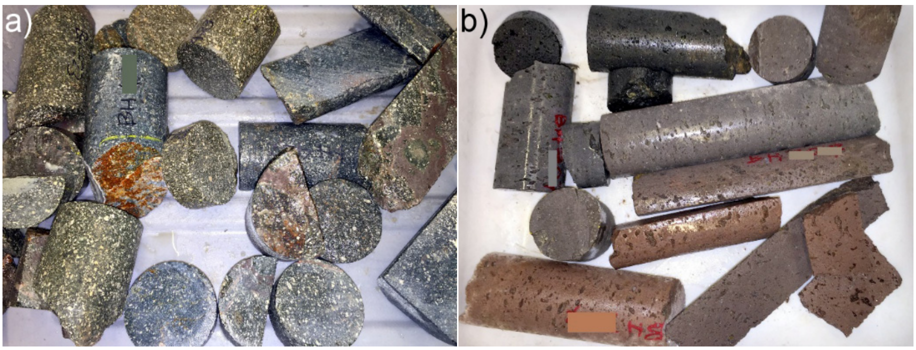

Figure 8: (a) Site 4 basaltic andesite porphyry, and (b) Site 7 vesicular trachyandesite.

Table 3: Physical test results.

Test	Site 4	Site 7
Specific Gravity	2.53	2.38
Absorption (%)	4.09	4.38
Micro-Deval Abrasion loss (%)	29.6	6.4
Unconfined Freeze-Thaw (% loss)	9.8	0.1
Magnesium sulphate soundness loss (%)	62.6	0.6
Petrographic Number (after CSA)	186	111

In parallel with the physical testing program, petrographic characterization, whole rock chemistry, and alkali-aggregate reaction testing were carried out. Select images are shown in Figure 9.

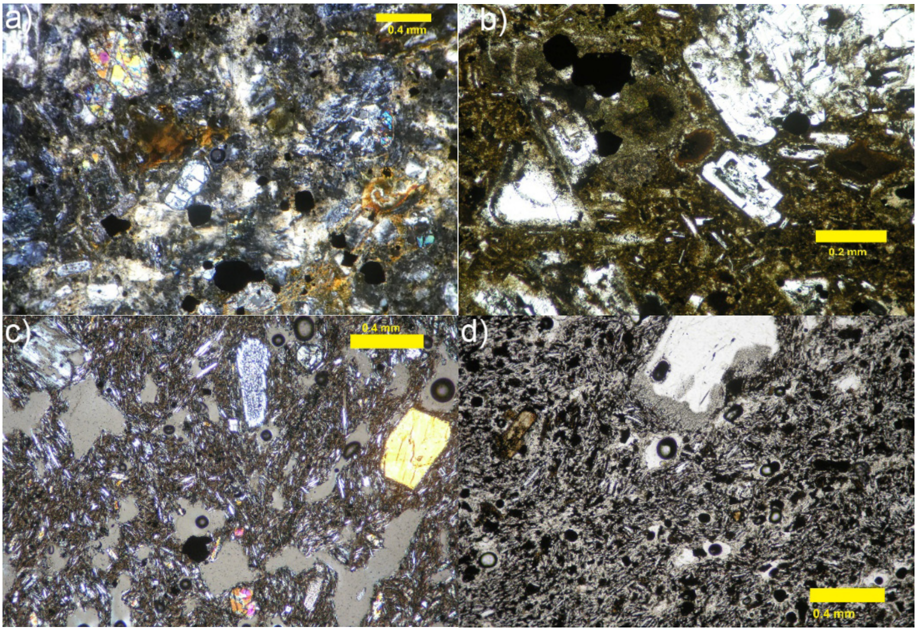

Figure 9: (a) Site 4 basaltic andesite porphyry, view in cross polarized light, 5x objective, (b) Site 4 porphyry, plane polarized light, 10x objective, (c) Site 7 vesicular trachyandesite, seen in cross-polarized light, 5x objective, (d) Site 7 trachyandesite, plane polarized light, 5x objective.

The Site 7 rock contained a variety of minerals in the vesicles, and glassy phases in the groundmass (Figure 10).

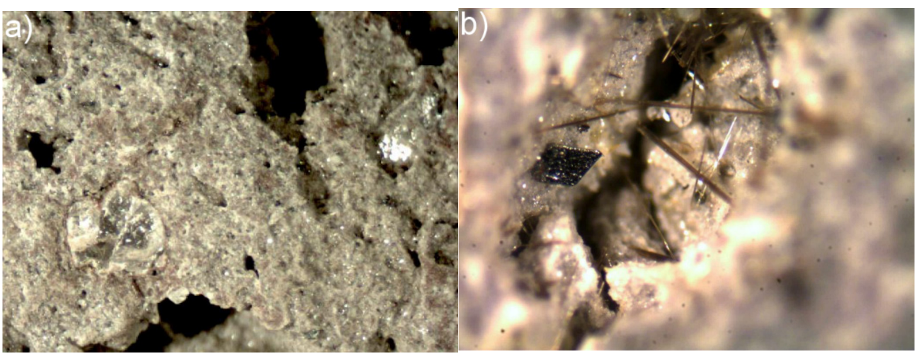

Figure 10: Stereomicroscope views of (a) Site 7 rock, field of view is 8.5 mm across, showing glassy texture, and (b) Site 7 rock showing zeolite needles in vesicle, field of view 2.2 mm across.

An important component of the suitability-for-concrete assessment was AAR testing. Composite samples of rock from each site were tested by AMBT (Table 4).

Table 4: AMBT results.

Source	14 d expansion (%)
Site 4	0.086
Site 7	0.686

Based on these data, the Site 7 trachyandesite rock was judged to have a high potential for AAR, while the Site 4 rock was considered to have a low AAR potential.

The challenge faced by these two alternative potential sources of concrete aggregate was that the site that showed the greatest durability, Site 7, also was the most reactive in terms of AAR. Conversely, the low quality rock, Site 4, exhibited a very low potential for AAR.

OVERVIEW

In both cases, the mining projects illustrate the following:

Short project timelines / schedules often constrain the ability of a fulsome investigation to be undertaken. This is often the case for the AAR testing, since 'definitive' testing almost invariably will require a minimum of one year of lead time to produce results. If evaluation of 'mitigative measures' in project concrete is required to evaluate the proposed use of SCMs to counter potential expansions due to AAR, a longer testing time – two years or more – may be needed. Project construction timelines are often far shorter than this, and decisions must be made on the basis of available information.

Frequently, the geology of minesites is characterized by mineralized rock – this is true of metals mines in particular, but also for coal mines and diamond mines. Awareness that metalliferous rock is likely to be proposed for use as an aggregate should be anticipated when conducting aggregate searches for mine construction. The presence of metallic minerals in unbound aggregates can be associated with environmental issues, such as Acid Rock Drainage (ARD) and metal leaching, and can also be associate with engineering issues such as heave. Finally, for use in concrete, the presence of certain metallic minerals – notably, pyrrhotite, marcasite and some forms of pyrite – can also be linked with curtailed durability and strength of concrete due to sulphate attack.

Petrography can provide a powerful tool for the assessment of the quality of materials that are proposed for use as aggregate on minesites. Particularly where a short timeline is required for such assessment, the use of thin-section analysis and scanning electron microscopy (SEM) can assist in these evaluations by providing geological insight into the nature of the materials that are under evaluation.

As with any investigation of potential construction materials, a measure of uncertainty may be experienced – resolving the uncertainty and developing sufficient and appropriate information upon which to base sound decisions is likely to involve some amount of 'outside-the-box' thinking and investigation.

Typical specifications that are applied to commercial aggregate supplies that serve urbanized settings can serve as "guidelines" for mining projects, but they may in practice be difficult, impractical or – in some cases-- impossible to achieve. Recognition of this concept can serve remote project developments well. For example, at some sites, washing aggregate materials to reduce the amount of material finer than 75/80 μm to a specific limit, such as 3%, may not be possible. Adjustment of concreting practices to accommodate a high-fines aggregate is often undertaken on remote sites. Likewise, the use of lower-than-desired durability aggregates can be challenging but with appropriate adjustment of concrete mixes, the use of such materials can prove successful.

CONCLUSION

These two mining project cases provide examples of typical issues that are encountered in the evaluation of proposed aggregate supplies at remote sites, often with limited access to resources, and often requiring pioneering approaches in engineering support.

Petrography remains an essential 'front-line' assessment tool in such evaluations, since it sets a direction for the course of further evaluation and testing. It can be used to eliminate some sources where there are multiples from which to select, and where economics of distance, routes and other technical characteristics are at play. For instances where options are limited, petrography can also provide input to projected performance.

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