Acid Rock Drainage Evaluation of Construction Aggregate Materials: Assessment of Petrographic Contribution

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Abstract
Testing of aggregate materials in connection with construction projects has traditionally involved ensuring that their engineering properties satisfy various specifications for durability, strength and resistance to various in-service considerations related to loading, abrasion, weathering and so on. Over the last few decades, however, it has become increasingly common to require supplemental evaluation that take into consideration the potential for Acid rock drainage (ARD) and metals leaching (ML) of aggregates.

Since most aggregate materials are composed of natural geologic products, having been produced from the sorting, crushing and washing of sand-and-gravel deposits or of crushed quarried rock, characterization of these materials has necessarily followed a geologic assessment-based route. Petrography plays an important role in the initial stages of the ARD/ML assessment and forms the basis for further testing.

In this paper, we present and discuss some cases of ARD prediction of aggregate materials that start with a mineralogical perspective.

Key words: petrography, aggregate, mineralogy, ARD prediction

Introduction

ARD and ML are not issues limited to mining operations, but can occur whenever sulphide-bearing rock material is exposed to the oxidizing environment. Examples will include not only an excavation into rock, such as in a rock cut for a roadway, railway, tunnel or slope, or in a mine, but also material excavated from a quarry or pit, and processed by means of size reduction (crushing) and screening to produce aggregate.

Depending on the nature of the project, several outcomes can result from the identification of the potential for ARD/ML. Material being tested may originate from an established source of aggregate, a proposed road rock cut, a potential tunnel site or from other proposed construction sites under investigation. If material from an aggregate source is identified as a potential source of ARD and/or ML, an alternative (innocuous) source may be selected as project aggregate supply. In the case of a road cut or tunnel, the material may be tested in order to determine both whether ARD/ML prone rock will be exposed and whether the material being removed can be used as construction aggregate elsewhere on the project, as a cost saving measure, or if it constitutes a potential environmental liability, which would require additional management and incur an additional cost to the project.

In the case of material proposed for use in concrete or asphalt, the ML properties of the material are typically not a concern, because the aggregate will be "encased" in the cement or asphalt binder matrix. Neither is the ARD potential of the material to be used in concrete a concern from an environmental point of view, because (1) the cement typically contains an abundance of components with neutralization potential for any acid produced, and (2) the pH of the concrete will generally be around 12.

However, from a concrete durability perspective, reactive sulphide content in the aggregate is a cause for concern. Oxidation of sulphides can cause concrete distress, because the reaction products associated with it occupy a larger volume than the reactants, thereby causing cracking. Softening of the cement paste can also be the result of the oxidation of sulphides contained in the aggregate. Reaction products include iron oxides, such as goethite, but also gypsum and ettringite, which can form when the sulphate ion produced

from the oxidation of the sulphide, reacts with components in the cement. Although closely related to ARD, this issue is a separate concern discussed elsewhere.

Background

The construction of Highway 97C in southern British Columbia in the late 1980s serves as an example of ARD that developed in connection with road construction, in this case, a rock cut. This caused the release of ARD and leaching of metals into a nearby creek.

Since that case, the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) has developed a policy for the prediction of ARD, technical circular T-10/04. It requires, as an initial assessment, that a professional geologist or engineer map a quarry being proposed as supply of aggregate or a proposed rock cut, whichever situation applies. During mapping - which can also include drilling - samples are obtained for petrographic examination. An appropriate number of polished thin sections are prepared and examined. The results from the petrographic examination determine whether further testing is required. Testing consists of static testing, such as acid-base accounting (ABA) and ML testing, using the shake flask extraction method (SFE), to further determine the potential for ARD/ML in a material upon exposure to the oxidizing environment in the presence of water.

In this paper we discuss some cases of testing of ARD potential in which petrography in conjunction with chemical analyses comprised the assessment. The prediction of ARD involves the balancing of the relative amounts of acid-producing minerals with that of neutralizing minerals. In the petrographic examination, the mineralogy of the sample is determined, including sulphide content, forms of sulphide, the presence or absence of calcite and other potentially neutralizing minerals, grain size and relative proportion of the observed minerals to assess its potential for ARD. The potential for ML is a more complex property to identify based on mineralogy alone, because minerals may contain trace elements that may pose an issue, in addition to the major components. Such trace elements are typically not identified unless the optical petrography is complemented by in-depth mineral specific analysis, such as by scanning electron microscopy (SEM). This is usually not undertaken in the investigation of ARD/ML potential in construction aggregate. Although most of the investigations described had an ML component, the focus for this paper is ARD prediction. All ARD testing was carried out using the Sobek method for determining the NP.

Case #1: Aggregate proposed for use as bridge end fill

Material from a quarry was proposed for use as bridge end fill at a new highway bridge construction project. As required by BC MoTI, the project specifications for aggregates included the need to conduct ARD/ML characterization of all fill aggregates to be used on the site, due to the nature of the project (i.e., construction of a span over a fish-bearing stream). The material from the quarry was found to consist of a series of volcanic rocks that had significant variations in their ARD characteristics.

Initial stockpile sample

One initial sample was collected from a stockpile. Petrographic examination, including thin section study, of the different components of the sample identified volcanic rocks with a wide array of compositions, including rhyolite, dacite, latite, trachyte and altered basalt, as indicated in Table 1. This table is extracted from a report on the Petrographic Examination (CSA A23.2-15A) of the sample. Such examination is routinely undertaken to assess the engineering suitability of geological materials proposed for use as aggregate in various applications.

Table 1. Lithologic composition of initial sample (based on Petrographic Examination), % by mass.

Conglomerate –volcanic clasts	0.2	**Latite**	22.2	**Dacite**	16.2
Metabasalt –porphyry, mafic	4.9	**Trachyte**	31.1	**Rhyolite**	10.1
Altered Latite	15.3				

The method includes lithological/mineralogical identification, assessment of physical competence of individual components and the identification of potential for chemical reactions when the material is used as construction aggregate. Such chemical reactions include (1) oxidation of sulphide that can produce ettringite formation in concrete, (2) ARD/ML for material exposed to environmental conditions and (3) alkali-aggregate reaction in concrete. The PN ("Petrographic Number") is a numerical measure of the physical quality/strength of a sample, calculated as the weighted average strength of the components. The calculation of the PN is given in CSA A23.2-15A, and is based on the sorting of the sample not only by lithology but also on the basis of engineering quality, and the assignment of the PN contributors 1,3, 6 and 10, which represent the quality "good", "fair", "poor" and "deleterious" respectively. Following sorting, the mass of each category is determined to the nearest 0.1 g, and the relative abundance of each category is calculated to the nearest 0.1%. The PN can range from "100" to "1000", typically a PN of 125 or less is considered to be an indication of good quality material. This sample had a PN of "110", thereby indicating that the crushed aggregate was projected to be of good physical (mechanical) quality.

As indicated in Table 2, pyrite was identified in four of the nine thin sections, in amounts that ranged from 3 to 15%, estimated visually. Calcite was present in some of the constituent rock types, but only in small amounts (1-2%). On a visual basis, it would not be expected that the calcite content in the overall sample would be sufficient to neutralize any acid that may form from the oxidation of pyrite in the aggregate.

Table 2. Mineralogical composition of the constituent rock types in the initial sample.

	Mineral species (visually estimated %) identified in thin section							
Tentative Rock Type	**Quartz**	**Feldspar**	**Mica**	**Chlorite**	**Epidote**	**Magnetite**	**Calcite**	**Pyrite**
Quartz latite/Rhyolite	10-20	80-90					<1	<1
Altered Andesite/Basalt	<1	90		2-3	5-10			<1
Altered Andesite/Basalt	10	70-75	8-14	4-6			1-2	<1
Rhyolite	30-35	50-55					<1	10-15
Rhyolite	30-35	50-55					<1	3-5
Altered Andesite/Basalt	10	70-75	1-3	4-5		10-15	<1	
Quartz trachyte	5	80-90						10-15
Quartz trachyte	5	80-90						5
Altered Andesite/Basalt	<5	55-65		30-40		<1	1-2	

Subsequent acid base accounting (ABA) testing confirmed this assessment and suggested that the material in the initial stockpile sample, identified as "WBG/BEF" in Table 3, would be considered as PAG (potentially acid generating material) material.

Table 3. Acid base accounting data for initial stockpile sample.

SAMPLE	**Description/ Lithology**	**NP ($tCaCO_3$/1000t)**	**S as sulphide (%)**	**Maximum Potential Acidity ($tCaCO_3$/1000t)**	**Ratio NP:MPA**
WBG/BEF	Initial stockpile sample	29	0.93	30	0.97

Sampling

Because the stockpile sample had a rather wide composition in terms of rock types, and recognizing that the stockpiled material might have had sources in multiple faces within the quarry, it was considered necessary to further identify the source locations for the different rock types and to determine whether the rock types that had a potential for ARD could be avoided during quarrying, so as to minimize/eliminate the content of ARD-producing material in the aggregate product.

During the subsequent visit to the quarry, we sampled additional stockpiles, undertook a more detailed study of the quarry faces and collected representative samples from several observation points along the quarry faces. Some of the sampling points, designated OP6-OP10, are illustrated in Figure 1 to Figure 6.

Figure 1. Stockpile from which one of the analyzed samples was taken.

Figure 2. Rock face at OP 6.

Figure 3. Location of OP7 and OP8.

Figure 4. View showing recently exposed rock face at OP 9 and OP10.

Figure 5. Location of OP9 at the very western end of the face containing OP7 and OP8.

Figure 6. Closer view of OP9 showing pyrite in both disseminated form and in veins (magnet for scale).

The sampling took place along a more or less continuous, roughly south-facing rock face. Some zones contained visible pyrite and some portions of the rock face exhibited rust staining, indicative of oxidation of the exposed rock material. The westernmost portion of the quarry face had been recently exposed and therefore, even though some of the rock material was found to contain pyrite, as shown in Figure 6, only minor rust staining had developed at the time of sampling. Visible pyrite was particularly abundant at OP9, which comprised a zone of veining and possible faulting, while the rock on either side, OP7 and OP10, contained no or little pyrite.

Outcrops east of the quarry face were also sampled; this area was also drilled as part of the quarry's exploration work prior to expansion of the quarry to the east.

Follow-up testing

The samples were subjected to whole rock analysis (WRA) using X-ray fluorescence and ABA testing. The results are discussed in the following sections.

Whole rock analysis

Based in part on the chemical composition presented in Table 4, primarily SiO_2 content, the sample from OP6 was determined to be rhyolite, OP 9 and 10 were classified as dacite, while the rocks at OP 7 and 8 were chemically most similar to andesite, as were the rocks in outcrop samples R1 and R2.

Table 4. Whole rock analyses for individual rock samples collected in the field.

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba(F)	LOI	Tot S
R1A	56.93	0.85	17.02	7.42	0.17	4.55	2.52	4.55	1.12	0.34	0.02	4.27	0.02
R1B	55.70	0.81	18.48	7.31	0.17	4.32	3.01	5.63	0.68	0.38	0.02	3.40	0.03
R2A	54.88	0.82	18.04	9.24	0.19	5.05	1.99	4.17	1.35	0.31	0.04	4.06	0.02
R2B	55.41	0.81	17.91	8.25	0.19	4.96	2.80	4.66	0.72	0.30	0.02	3.82	0.02
R2C	59.91	0.72	16.30	7.27	0.17	3.78	3.96	3.92	0.71	0.29	0.02	3.06	0.08
OP6	70.54	0.46	14.22	3.27	0.07	1.20	0.77	5.99	0.93	0.16	0.02	1.61	0.16
OP7	58.13	0.60	15.49	7.10	0.30	4.27	3.21	4.19	1.81	0.15	0.14	4.63	0.10
OP8	57.48	0.61	15.05	7.11	0.23	2.81	4.55	3.08	2.39	0.15	0.10	5.14	0.29
OP9	66.53	0.46	9.95	9.41	0.16	2.30	0.96	2.51	1.57	0.24	0.15	4.88	4.90
OP10	68.01	0.49	14.33	3.96	0.10	1.56	1.87	6.07	0.74	0.14	0.03	2.26	0.03

Total sulphur content ranged from 0.02 percent, in the outcrop in the eastern part of the quarry, to 4.9% at OP9. It would appear the elevated levels of sulphur are primarily associated with the veining observed in the dacite at OP9. Andesite at OP8 may also have contained some pyrite, while andesite in the eastern portion of the quarry did not contain elevated levels of sulphur indicative of pyrite. This confirmed the observation made in the field that the sulphide content of the rocks was controlled by the presence of sulphide veining rather than by a difference in sulphide content in the rock types themselves.

ABA testing

Results from the ABA testing are presented in Table 5. Comparison with criteria set forth by Price (2009) indicated that two samples in Table 5 would be considered to be PAG material, one of the subsequent stockpile samples, BEF #4, and the sample collected at OP 9. All other samples were well within the limits of what would be considered to be non-PAG material. Some of these samples contained some pyrite, which was balanced by the content of neutralizing material in the rock material to produce a net non-PAG result.

Table 5. Acid-base accounting data for outcrop samples and stockpile samples.

SAMPLE	Description/Lithology	NP ($tCaCO_3$/1000t)	S as sulphide (%)	MPA ($tCaCO_3$/1000t)	NP:MPA (no units)
WBG/BEF	Initial stockpile sample	29	0.93	30	**0.97**
BEF#2	Subsequent stockpile sample	17	0.01	1.9	9.07
BEF#4	**Subsequent stockpile sample**	26	0.98	31.3	**0.83**
OP 7+8	andesite	67	0.09	3.4	19.49
OP 9	**dacite**	17	5.56	176.3	**0.1**
OP 10	dacite	47	0.04	1.6	30.08
DH Sa. 1	andesite	16	0.02	0.9	17.07
DH Sa. 2	andesite	18	0.01	0.6	28.8
R1	andesite	16	0.02	0.6	25.6
R2	andesite	21	0.02	0.9	22.4

During our field visits, we did not observe any sulphide veining in the eastern quarry faces. None of the rock types in this portion of the quarry were considered to be potentially acid-generating, including the drillhole samples. This would indicate that sulphide veining did not extend into this portion of the quarry.

With a combined approach of mapping, petrography and chemical analysis, we were able to identify the source of the PAG material in the stockpile material, and provide direction regarding selective extraction of non-PAG material.

Case #2: Road cut along Highway 1

A portion of Highway 1 near Golden, BC was undergoing re-construction in order to realign a curved section and decrease the grade of the road. As a result, new road cuts were to be created in order to accommodate the new alignment of the road. Drilling was conducted and the obtained core material was examined and analyzed with respect to ARD.

Rock characteristics

The material consisted of medium to dark grey calcareous metamudstone with a grain size that varied from silt- to clay-size. Some of the material exhibited banding and lamination, while other sections were more massive in appearance, as shown in Figure 7 and Figure 8. Major mineral constituents were quartz, calcite and a very fine grained clay phase, which, by means of X-ray diffraction, was found to consist of muscovite, clinochlore and feldspar.

Calcite content was variable within the rock core, but calcite was found in thin section to be a major mineral in all samples examined. In addition, calcite veining was common throughout. Pyrite occurred in amounts of less than one to two percent and had a grain size of 1 – 10 µm. Pyrite occurred in accumulations that often were associated with fossil fragments, as illustrated in Figure 9, and was typically anhedral, sometimes in a framboidal form. Euhedral pyrite, which is considered to be more stable and less likely to oxidize, was not common. It would therefore be expected that most of the pyrite would undergo oxidation over time upon exposure to atmospheric conditions.

Figure 7. Core section with thinly laminated mudstone and some, mostly thin, calcite veining

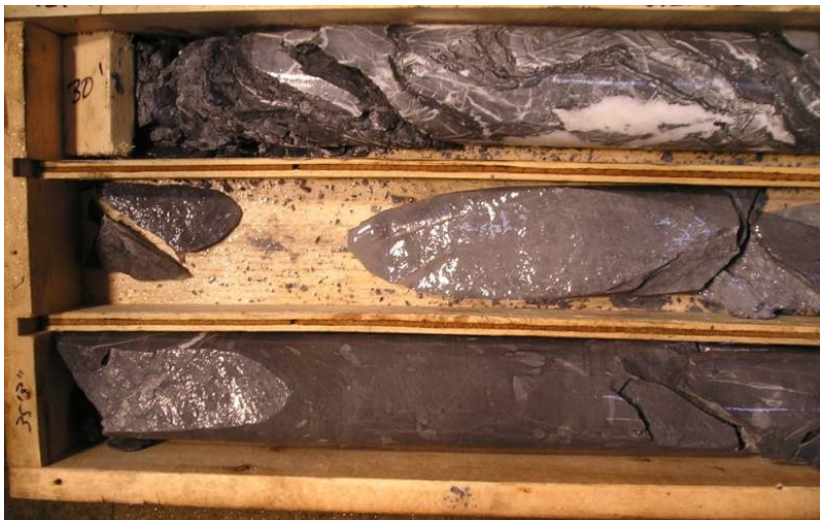

Figure 8. Section of core containing heavily calcite veined mudstone on top of the photo and more massive metamarlstone on the bottom of the photograph.

Some oxidation of pyrite was noted in thin section, and in addition, some rust staining was noted on fracture planes in the rock, as illustrated in Figure 7. However, with the abundance of calcite present, it was predicted that the net result would suggest non-PAG conditions. Because of this, the number of samples submitted for ABA testing was limited to three.

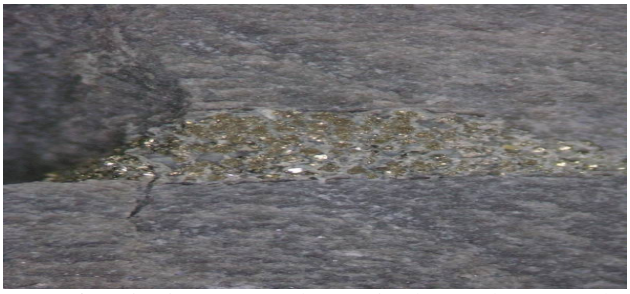
Figure 9. Typical occurrence of pyrite in metamudstone in the study area. The field of view is 4.5 mm, 20x magnification.

Acid-base accounting
Sample 1 was a metaclaystone, which was typically darker grey and lower in observed calcite content than many other samples in the investigation; pyrite content tended to be slightly higher in this rock type. The metamarlstone represented by sample 5 was more calcareous (as the term "marl" indicates) and contained smaller amounts of pyrite. This is reflected in the ABA results provided in Table 6. Comparison with criteria proposed by Price (2009) indicates that all the samples would be considered to be non-PAG material. The ABA results were well supported by petrographic observations.

This example was fairly straightforward in terms of ARD prediction using petrography, because of the abundance of calcite and relative homogeneity of the rock material. Therefore, ABA testing was undertaken only to confirm the petrographic observations, using a small number of samples.

Table 6. Summary of three ABA testing results and the corresponding lithology of the samples.

SAMPLE	Lithology	NP ($tCaCO_3$/1000t)	Sulphur as sulphide (%)	MPA ($tCaCO_3$/1000t)	NP:MPA (no units)
1	Metaclaystone: Medium to dark grey, very fine grained and calcareous. Laminated with a greasy feel on lamination surfaces. Very frequent fractures parallel to lamination - fissile.	180	0.16	5	36
3	Metasiltstone/metaclaystone: Grey, calcareous with clay lamination. Heavily laminated and with frequent calcite-quartz veins	250	0.14	4.4	57.1
5	Metamarlstone: Light grey, very fine grained. Laminated, breaks apart parallel to laminae.	344	0.08	2.8	122.3

Case #3: Tunnel project on the Sunshine Coast, British Columbia
Material obtained during exploratory drilling, as part of a pre-construction investigation for a planned tunnel project, was submitted for petrographic examination. The client wanted to know whether rock material extracted during the construction of the tunnel would be a concern with respect to ARD, since its re-use as construction aggregate would benefit the project's engineering practicalities and economics.

Thin section analysis
We carried out thin section analysis on four samples. The rock types identified were granodiorite and diorite. Dominant minerals in the granodiorite were plagioclase and quartz, while in the diorite samples it was plagioclase and hornblende. Accessory minerals included apatite, chlorite, calcite, sericite /muscovite and sphene.

A summary of the thin section analyses is provided in Table 7, and Figure 10 to Figure 13 provide thin section photographs. The granodiorite was found to contain pyrite in amounts of less than 1%, while the

diorite sample contained sulphide minerals, consisting of pyrite and minor chalcopyrite, which ranged in abundance from less than one percent to 2%. The pyrite content was consistently about 1%, based upon visual estimates. This suggested that the granodiorite would not constitute a concern with respect to ARD, whereas the combination of the presence of pyrite and absence of carbonate minerals in the diorite may indicate that this was PAG material.

Table 7. Summary of thin section analyses of rock material from proposed tunnel, Sunshine Coast, BC. Abbreviations for mineral names in this table are used in Figure 10 to Figure 13.

	Mineral composition (visually estimated % range)						
Sample	**Quartz (Qz)**	**Plagioclase (Fsp)**	**Hornblende (Hbl)**	**Biotite (Bi)**	**Epidote (Ep)**	**Magnetite-ilmenite**	**Pyrite (Py)-chalcopyrite**
Granodiorite	30-40	35-40	6-10	10-15	1-2	1	<1
Diorite 1	0-10	20-55	30-60	<1		3-6	<1-2
Diorite 2	2-10	10-35	40-70	<1-4		1-5	<1-1
Diorite 3	2-3	40-50	30-40	4-8		3-5	1-2

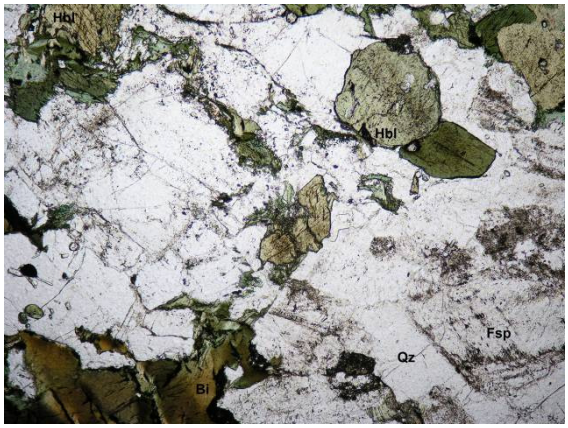

Figure 10. General view of the granodiorite in plane polarized light (PPL), 50x magnification, 2.4 mm (left to right) field of view (FOV).

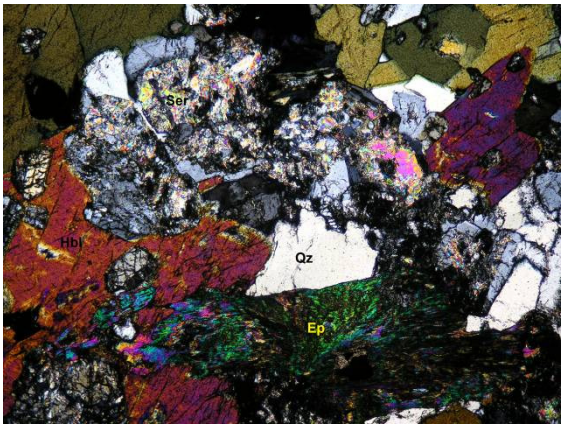

Figure 12. Diorite, 50x, XPL, 2.4 mm FOV.

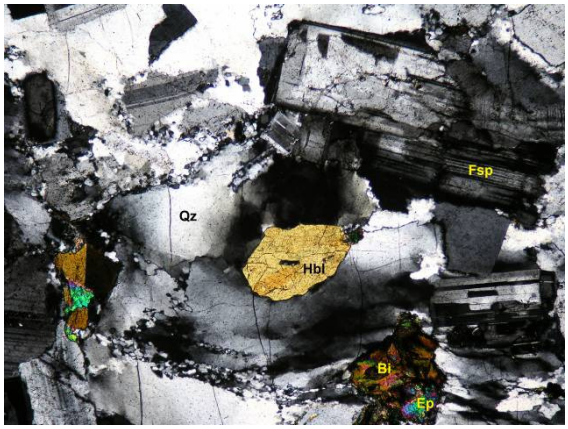

Figure 11. Granodiorite in cross polarized light (XPL), 50x, 2.4 mm FOV.

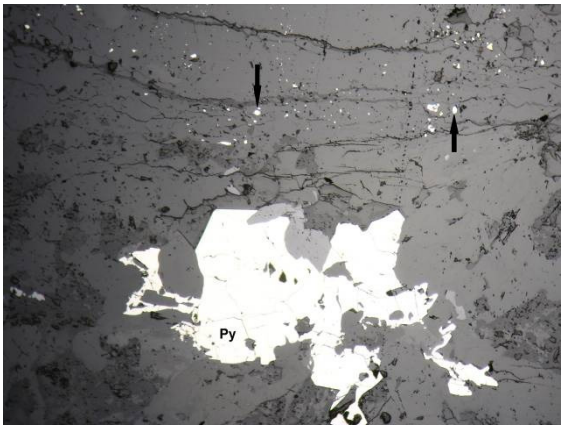

Figure 13. Diorite in reflected light, showing pyrite, ("Py") (see arrows). 50x, 2.4 mm FOV

Acid-base accounting

We undertook ABA testing of the three diorite samples and the granodiorite sample. A comparison of the NP:MPA ratio for the granodiorite with the criteria given in Price (2009) confirmed that the granodiorite was non-PAG material. However, it was found that the neutralization potential in the diorite samples might not be enough to balance its MPA, as indicated in Table 8. Two of the three samples would plot just outside of the PAG field, whereas one sample would be considered 'uncertain' with respect to its ARD potential. The use of the sulphide sulphur values instead of the MPA in the assessment would improve the ratio for the diorite samples, such that the bulk average ratio would be larger than 2.0, which would be considered a non-PAG result. However, there was no indication of the relative proportions of the three types of diorite. Without that knowledge, we could not assume that the bulk diorite would be non-PAG.

Table 8. Summary of ABA data for rock material from planned tunnel, Sunshine Coast.

SAMPLE	NP ($tCaCO_3$/1000t)	Sulphur as sulphide (%)	MPA ($tCaCO_3$/1000t)	NP:MPA (no units)
Granodiorite	10	<0.01	0.3	32
Diorite 1	13	0.16	5.6	2.31
Diorite 2	12	0.15	5.3	2.26
Diorite 3	13	0.23	8.1	1.6

It should be noted that the maximum potential acidity is based on the total sulphide sulphur content. This value includes sulphur present in chalcopyrite, which is not acid-producing to the same extent as pyrite. It is possible that refinement of the sulphide speciation using a larger number of thin sections might indicate that the diorite was not a PAG-material. Additional thin-section characterization and supplemental testing such as humidity cell testing was not undertaken to refine the initial findings. As is often the case with construction projects, the time frame of the project did not allow for such in-depth analyses.

It was therefore suggested that, depending on the relative proportions of the two rock types, blending of the two rock types may produce net neutralizing conditions in the rock material with a margin of safety that took into account the uncertainties in the analytical methods. Another alternative would be to utilize the material as asphalt aggregate or concrete aggregate, for use by local contractors.

Case #4: Sand and gravel from a pit in coastal British Columbia

In addition to rock materials -- be it quarried crushed rock, drill core or grab samples -- sometimes sand and gravel samples are submitted for ARD/ML assessment; in such cases, ABA testing may be conducted as part of an annual concrete aggregate testing program.

Gravel samples typically consist of a mixture of several rock types which can originate from geologically and mineralogically diverse formations within which the ARD characteristics may also vary. Table 9 provides ABA results for a series of products from a pit in coastal BC. The different products from this pit had NP:MPA ratios that ranged from 3.56 to 25.6. The sulphide content was seven times higher in the coarsest product than in the fine sand, while the neutralization potential varied only by a factor of 2.5 between the different samples and was almost constant in the coarse products.

The main rock type components in the samples from the pit were plutonic rocks, primarily granite and granodiorite, with a small amount of diorite, mixed with volcanic rock types, primarily basalt and andesite. In the sand products, the proportion of single mineral grains, consisting mainly of quartz and feldspar, was significant. Quartz, which accounted for 67% of the fine sand, can be considered inert with respect to ARD, which is reflected in the very low NP and MPA. While the different stone products contained similar proportions of plutonic to volcanic rock types, the total sulphur and sulphide content in the individual components created significant variability in the ABA results.

Table 9. Variation of ARD properties for six different products from the same pit and drillhole samples from a proposed aggregate source.

SAMPLE	NP ($tCaCO_3$/1000t)	Total sulphur (%)	S as sulphide (%)	S as sulphate (%)	MPA ($tCaCO_3$/1000t)	NP:MPA (no units)
28 mm stone	10	0.09	0.07	0.02	2.8	3.56
20 mm stone	11	0.06	0.05	0.01	1.9	5.87
14 mm stone	11	0.03	0.02	0.01	0.9	11.73
"Birdseye"	7	0.06	0.05	0.01	1.9	3.73
Coarse sand	6	0.01	0.01	<0.01	0.3	19.2
Fine sand	4	<0.01	<0.01	0.01	<0.3	25.6

Because of the complexity of sand and gravel materials and variability in ARD properties demonstrated by the data in Table 9, petrography, as a detailed ARD prediction tool for sand and gravel, is typically a more time consuming task than when working with rock material. Thus, while petrography presents an effective tool for assisting and providing direction in ARD assessments of more geologically homogeneous materials, its effectiveness in assessments of geologically diverse materials such as sand-and-gravel aggregates is limited.

Summary

We have presented a few cases of analytical investigation of the potential for ARD of a variety of materials. These cases all included petrographic examination in combination with chemical testing. Petrography is an important and reliable tool in the identification of PAG material, when carried out by an experienced petrographer. In addition to determining the relative amounts of acid-generating material and neutralizing material, the petrographer can also provide insight about:

- Sulphide species – some sulphide minerals, such as pyrite, marcasite and pyrrhotite, are more reactive/prone to oxidation than others.
- Crystal form – anhedral and framboidal pyrite is more prone to oxidation than euhedral pyrite, both due to larger exposed surface area and a less ordered and stable crystal structure (INAP, 2009).
- Grain size – larger particles have a smaller exposed surface area than smaller particles (Smith and Beckie, 2003). Therefore, the grain size of the material in a particular end use also needs to be taken into consideration.
- Distribution – pyrite can be evenly disseminated or concentrated along veins. Veins also tend to be planes of weakness and therefore, after crushing, pyrite may become preferentially exposed on particle surfaces. This could increase the availability of pyrite as compared to what the measured average pyrite content would indicate.

As Case #1 illustrates, the sampling is a crucial part of the investigation. In this situation, where pyrite content varied significantly and abruptly, such as was the case of the pyrite veining, detailed mapping was essential. It is therefore important that sampling is undertaken by personnel who have a thorough understanding of the importance of geological aspects of the sampling, so that (1) samples that are representative of the source material are obtained, and (2) that extremes in terms of sulphide minerals and potentially neutralizing minerals are also represented in the samples and properly documented. All too often, the samples are procured by those with minimal understanding of ARD/ML, site geological conditions and the appropriate sampling protocols.

Case #3 exemplifies the difficulties in providing appropriate insights to a project without contextual information about the project itself.

It is recognized that these investigations were largely preliminary in nature, and if material was to be properly characterized with respect to the individual project concerns, further testing and project specific conditions would have to be taken into consideration.

We have found that factors other than the geological and mineralogical characteristics of the rock material itself should be taken into consideration, including:

- Particle size of the end use material
- Service environment
- pH and chemical composition of surface and groundwater and soil in the receiving area

These are factors that determine the result of the interaction between the geological material and the environment in which it is used or deposited. In many cases where these aspects are not known, only the factual findings of the investigation can be provided. Interpretation of the data then becomes an item which may be based upon the analyses, but will typically require additional input. This input includes information on the relative proportions of the different rock types, their spatial relation to each other and distribution of sampling points.

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