

USING HYPERSPECTRAL SCAN & QXRD MINERALOGY FOR AMD HAZARD ASSESSMENTS AT BHP IRON ORE OPERATIONS

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ABSTRACT

BHP routinely collects hyperspectral scan (HScan) mineralogy for exploration drill hole materials at WAIO operations in the Pilbara, Australia. To assess the accuracy of HScan mineralogy and identify opportunities to use this data in-lieu of static geochemical and/or QXRD data, HScan mineralogy was compared with Quantitative X-Ray Diffraction (QXRD) mineralogy for 214 selected samples. In addition, a subset of samples (n = 80) was also subject to conventional static geochemical characterisation (e.g., paste pH/EC, ANC, Total S, ABCC). The advantage of using HScan data is that it provides a large number of data points that can be used to infer the geochemical properties of a material, thus dramatically expanding the dataset available to assess geochemical behaviour and verify BHP's algorithm-based AMD classification system against measured geochemical properties.

HScan identified 21 minerals in the Pilbara and provides information on non-crystalline (e.g., organic matter) and poorly crystalline phases (e.g., goethite crystallinity), whereas QXRD identified 28 minerals and the proportion of amorphous phases.

The accuracy of HScan and QXRD mineralogy was found to increase with the concentration of the target mineral. HScan quantifies the concentrations of Fe / ore minerals (hematite, goethite) with accuracy approximately equal to QXRD. However, QXRD has lower limits of detection, and therefore provides more accurate quantification of minerals with low concentrations, which in the Pilbara is often those with acid generating or neutralising capacity. For AMD hazard classification, QXRD identified sulfide minerals (e.g., pyrite / marcasite) as the dominant contributor to the MPA of most samples, with lesser secondary acid generating sulfate minerals (e.g., alunite, jarosite, szomolnokite). In contrast, HScan identified alunite as the only acid generating mineral. Both mineralogical techniques (HScan and QXRD) identified ANC providing carbonate minerals (e.g., calcite, dolomite), although with limited consistency between either of the mineralogical techniques assessed and conventional static geochemistry.

QXRD has the potential to provide the most accurate AMD hazard assessment (lower detection limits / identification of sulfides). Nonetheless, there are several benefits to be gained by utilising the HScan and XRF datasets for AMD classifications, if extensive datasets are already available. The total sulfur from XRF, less sulfate sulfur (calculated from alunite measured by HScan), allows estimation of the residual (un-specified) sulfur which is conservatively assumed to be pyrite.

A subset of 80 samples, was used to compare the different methods of assessing AMD hazards. BHP's current AMD hazard classification algorithm returned the highest number of samples classified as PAF (i.e., 80/80; the most conservative approach). In contrast, conventional static geochemistry (ie. laboratory measured ANC) returns a lower number of samples classified as PAF (i.e., 60/80). AMD hazard classifications based on mineralogical data (i.e., QXRD and HScan + XRF sulfur) provide intermediate and similar proportions of samples classified as PAF (ie., 70/80 and 67/80, respectively). Hence, when supplemented with XRF sulfur HScan can be used to validate BHPs AMD hazard classification system.

Keywords: AMD Classification, Mineralogy, Hyperspectral Scan, X-Ray Diffraction

1. INTRODUCTION

Conventionally, the Acid and Metalliferous Drainage (AMD) hazard posed by a material has been assessed using static geochemistry (i.e., compositional data). For example, total sulfur may be measured by XRF, and it is commonly assumed that all sulfur is bound in the mineral's pyrite / marcasite [FeS_2] – the most abundant acid generating sulfide minerals in the Pilbara. However, in materials where some of the sulfur is bound in minerals that generate less acidity per mole than pyrite (e.g., alunite [$\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$]) or are non-acid generating (e.g., gypsum [$\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$]), this approach will overestimate the Maximum Potential Acidity (MPA). Therefore, laboratory based selective extraction techniques were developed in an attempt to estimate sulfur speciation (e.g., S_{Cr} , S_{HCl} , S_{KCl}). Likewise, the abundance of carbonate minerals that provide acid neutralisation capacity (e.g., calcite [CaCO_3] or dolomite [$\text{CaMg}(\text{CO}_3)_2$]) is commonly estimated based on titration of the sample with strong acid. Ultimately, these laboratory-based techniques measure chemical properties that enable estimation of specific mineral concentrations.

Direct mineralogical analyses (e.g., Quantitative X-Ray Diffraction [QXRD]) have not typically been undertaken during routine AMD hazard assessments. This is because, historically, small samples sizes that are not representative were used (i.e., $\sim 0.1\text{g}$), limits of detection were not sensitive enough for environmental purposes ($\sim 1\text{ wt.}\%$), and analyses were time consuming and expensive compared with conventional static testwork. However, over the last two - five years there have been substantial advances in techniques used to collect mineralogical data, as well as the development of new techniques for mineralogical determinations, such as those based on spectral analyses (e.g., Hyperspectral Scanning [HScan]). For example, QXRD now uses sample sizes (i.e., 1-20g) that are similar or larger than those used for compositional analyses (XRF), detection limits of new generation instruments are similar to conventional XRF ($< 0.1\text{ wt.}\%$), and the time required for analyses has decreased from a matter of an hour to a few minutes.

Since 2016, BHP Western Australia Iron Ore (BHP WAIO) has routinely collected hyperspectral (HScan) mineralogy data on exploration drill hole materials. This large mineralogical database has applications for mining and exploration purposes (ore grade control / definition and geological interpretation). However, it was unclear whether this large existing HScan mineralogy dataset could be used to validate the AMD hazard classifications used at BHP, which is currently validated via traditional static testwork.

Theoretically, direct measurement of a materials mineralogy, which provides full (or partial) speciation of the sulfur- and carbon-bearing minerals, should yield the most accurate indication of environmental behaviour and the AMD hazard. To assess the accuracy of BHP's existing hyperspectral scan (HScan) mineralogy data at WAIO operations in the Pilbara, HScan mineralogy was compared with QXRD mineralogy, and with conventional laboratory based static geochemistry (e.g., paste pH/EC, ANC, ABCC) for 214 selected samples.

2. BACKGROUND

BHP WAIO currently define the Acid and Metalliferous Drainage (AMD) hazard of waste rock samples based on a series of algorithms that estimate MPA and ANC from primary assay data, which is routinely collected for waste and ore materials. The AMD classification embedded in all distribution models, is routinely confirmed, and validated using conventional static geochemical tests conducted on selected samples. This may include

total sulfur, ANC, NAG_{pH} , leach tests, bulk geochemistry, ABCC, and QXRD. However, the number of samples submitted for verification analysis on an annual basis pale in comparison to the number of samples that undergo HScan. Therefore, if HScan data were sufficiently accurate, the number of datapoints that could be used to validate AMD hazard classifications would increase by many orders of magnitude.

3. METHOD

3.1. Sample Selection

Samples were selected from an existing geochemical (XRF major element - Fe, P, SiO_2 , Al_2O_3 , CaO, Mn, MgO, TiO_2 , K_2O , S, Na_2O , LOI) and HScan mineralogy database. From this database 214 samples were selected, with the view to cover various Proterozoic and Tertiary Detrital stratigraphic units, multiple iron ore deposits across the Pilbara, samples from above and below the water table (a proxy for weathering), as well as samples with a wide range of total sulfur concentrations (reflecting MPA values) and calculated ANC contents.

3.2. Data Collection

All 214 samples were subject to high precision QXRD analysis, to allow direct comparison with existing HScan mineralogy. Based on initial assessments of the existing geochemistry and new mineralogical data, a subset of samples was subject to additional static geochemistry analyses, including paste pH and EC ($n = 147$), ANC and carbon speciation [Total Carbon, Total Inorganic Carbon, and Total Organic Carbon] ($n = 80$), siderite corrected ANC ($n = 12$), and Acid Buffering Characteristics Curve (ABCC; $n = 6$).

These additional static geochemistry analyses were conducted to understand the relationship between the measured mineralogy (HScan / QXRD), and the laboratory tests designed to classify AMD hazards. For instance, to understand how laboratory-measured ANC via titration of a pulped sample with a strong acid relates to the concentration of carbonate minerals that provide ANC (measured by HScan / QXRD). Or to understand how paste pH values relate to concentrations of sparingly soluble acid generating minerals (alunite and jarosite), highly soluble acid generating minerals (szomolnokite and rhomboclase), and carbonate minerals that provide ANC (calcite, dolomite).

3.3. Data Assessment

3.3.1. Comparison of QXRD and HScan Mineralogy

The first stage of this study involved direct comparison of QXRD and HScan mineralogy. It is important to note that not all minerals identified by QXRD were also identified by HScan, and *vice versa*. Hence the relative accuracy of these techniques is only assessed for minerals identified by both analytical techniques. Moreover, in some instances, multiple polymorphs of the same phase were detected by QXRD (e.g., aragonite and calcite [CaCO_3], pyrite and marcasite [FeS_2]). In this contribution, these polymorphs are considered collectively as a single mineral for the purposes of plotting and data comparison.

For an additional and independent point of comparison, the mineralogy (HScan and QXRD) was used to calculate a bulk geochemical composition, assuming that all minerals have ideal stoichiometric compositions (see Table 1 below). The bulk geochemical compositions calculated from mineralogy data were then compared with bulk geochemical compositions measured by XRF.

3.3.2. AMD Hazard Classification - Mineralogy vs. Static Geochemistry.

Common acid-base accounting parameters (MPA, ANC, NAPP) were calculated based on the following:

1. BHP WAIO's current classification system (see Section 2).
2. QXRD mineralogy.
3. HScan mineralogy.
4. HScan mineralogy plus total sulfur (XRF).

It is important to recognise that HScan did not detect pyrite / marcasite in the current samples, but rather alunite was the only acid generating phase identified. In contrast, QXRD also identified pyrite / marcasite as the main contributor to the MPA values of many samples. In order to overcome the fact that HScan only provides partial sulfur speciation (detection of alunite, but not pyrite / marcasite), the sulfur bound in alunite (measured by HScan) is calculated and subtracted from XRF total sulfur, yielding 'residual' sulfur. It is then assumed that this residual sulfur (i.e., the difference between sulfur bound in alunite [HScan] and total sulfur [XRF]) is bound in minerals pyrite / marcasite.

Conversion of mineralogical data to static geochemistry in order to generate AMD hazard classifications was automated using software (ImpactScan), and these measured static parameters were compared with those inferred from BHP's algorithms.

4. RESULTS AND DISCUSSION

4.1. Comparison of HScan and QXRD mineralogy

HScan mineralogy identified 21 individual minerals, various mineral sub-types (e.g., vitreous and ochreous goethite; poorly crystalline, well crystalline, and Fe-rich kaolinite), as well as quantification of non-crystalline phases (e.g., organic content). In contrast, QXRD identified 28 minerals, including multiple polymorphs of the same mineral, and amorphous content (see Table 1).

The minerals identified by HScan, but not by QXRD include: rhodochrosite, palygorskite, apatite, pyrolusite, cryptomelane, ferroan dolomite (ankerite), Fe-smectite (nontronite), and amphibole (Table 1). Although in most samples HScan returns zero values or very low concentrations (0.1 or 0.2 wt.%) for these minerals. Whilst ankerite provides some acid neutralising capacity, the low concentrations measured by HScan have limited impact on the results of Acid Base Accounting (ABA) calculations or AMD hazard classifications.

Minerals identified by QXRD but not by HScan include: anatase / rutile, aragonite, gypsum, illite, jarosite, maghemite, pyrite / marcasite, orthoclase / microcline, rhomboclase, sphalerite, and szomolnokite. The inability of HScan to identify various acid generating phases, particularly pyrite, but also jarosite, rhomboclase and szomolnokite, or aragonite (acid neutralising) directly influences ABA calculations and potentially AMD hazard classifications.

In general, the correlation between HScan and QXRD mineralogy improves as the concentration of the target mineral increases. Accordingly, the correlation between HScan and QXRD mineralogy is generally linear ($R^2 > 0.75$), and approximately 1:1 for major ore / rock forming minerals (i.e., hematite, goethite, siderite, kaolinite, and quartz). However, as the concentration of the target mineral decrease, so does the correlation between these two mineralogical techniques (e.g., Figure 1).

The QXRD limit of detection (LOD) is ~0.1 wt.%. Whilst the HScan LOD is also 0.1 wt.%, the accuracy of concentrations below ~5wt.% is limited. For instance, multiple samples contain up to 5 wt% alunite according to QXRD measurements, which is supported by the XRF bulk chemistry (i.e., elevated concentrations of K, Na, and S, in ratios indicative of an alunite-natroalunite solid solution). However, HScan does not identify alunite in the majority of these samples.

Table 1 Summary of the minerals identified by HScan and QXRD. Those shaded orange are acid generating minerals, and those shaded blue are acid neutralising minerals. Minerals identified by both techniques are highlighted by bold text.

HScan Minerals	QXRD Minerals	Stoichiometric Formula
Alunite	Alunite	KAl₃(SO₄)₂(OH)₆
	Jarosite	KFe ³⁺ ₃ (SO ₄) ₂ (OH) ₆
	Marcasite	FeS ₂
	Pyrite	FeS ₂
	Rhombochase	HFe ³⁺ (SO ₄) ₂ ·4(H ₂ O)
	Szomolnokite	Fe ²⁺ SO ₄ ·(H ₂ O)
	Aragonite	Ca(CO ₃) ₂
Calcite	Calcite	Ca(CO₃)₂
Dolomite	Dolomite	Ca,Mg(CO₃)₂
Ferroan dolomite (ankerite)		Ca(Fe ²⁺ ,Mg,Mn)(CO ₃) ₂
Al-smectite (montmorillonite)	Montmorillonite	(Na,Ca)_{0.3}(Al,Mg)₂Si₄O₁₀(OH)₂·n(H₂O)
Amphibole (riebeckite)		Na ₂ Fe ²⁺ ₃ Fe ³⁺ ₂ (Si ₈ O ₂₂)(OH) ₂
Apatite		Ca ₅ (PO ₄) ₃ (OH,F,Cl)
Chlorite (clinochlore)	Chlorite (clinochlore)	(Mg,Fe²⁺)₅Al(Si₃Al)O₁₀(OH)₈
Cryptomelane		K(Mn ⁴⁺ ,Mn ²⁺) ₈ O ₁₆
Fe-smectite (nontronite)		Na _{0.3} Fe ³⁺ ₂ (Si,Al) ₄ O ₁₀ (OH) ₂ ·n(H ₂ O)
Gibbsite	Gibbsite	Al(OH)₃
Goethite	Goethite	Fe³⁺O(OH)
Hematite	Hematite	Fe³⁺₂O₃
Kaolinite	Kaolinite	Al₂Si₂O₅(OH)₄
Palygorskite		(Mg,Al) ₂ Si ₄ O ₁₀ (OH) ₄ ·4(H ₂ O)
Pyrolusite		MnO ₂
Quartz	Quartz	SiO₂
Rhodochrosite		MnCO ₃
Siderite	Siderite	Fe²⁺(CO₃)
Stilpnomelane	Stilpnomelane	K(Fe²⁺,Mg,Fe³⁺)₈(Si,Al)₁₂(O,OH)₂₇·n(H₂O)
White mica (muscovite)	Muscovite	KAl₂(Si₃Al)O₁₀(OH,F)₂
	Anatase	TiO ₂
	Rutile	TiO ₂
	Gypsum	CaSO ₄ ·2(H ₂ O)
	Illite	(K,H ₃ O)(Al,Mg,Fe) ₂ (Si,Al) ₄ O ₁₀ [(OH) ₂ ·(H ₂ O)]
	Maghemite	Fe ³⁺ ₂ O ₃
	Magnetite	Fe ²⁺ Fe ³⁺ ₂ O ₄
	Microcline	KAlSi ₃ O ₈
	Orthoclase	KAlSi ₃ O ₈
	Sphalerite	ZnS

4.2. Comparison of Mineralogy (HScan & QXRD) and Major Element Geochemistry (XRF)

Comparison of the major element geochemistry measured by XRF, with the major element geochemistry calculated from mineralogy data (HScan and QXRD) confirms that the accuracy of mineralogical determinations increases as the concentration of the target mineral increases (as noted above).

HScan mineralogy can be used to quantify the concentrations of elements such as iron and silica, as well as LOI with accuracy generally equal to that of QXRD mineralogy, where both techniques are in good agreement with the measured XRF data (e.g., Figure 2). These elements are important for grade control, geological interpretation, and exploration purposes.

The accuracy of HScan mineralogy for calculating the concentration of elements such as calcium, magnesium, potassium, and sulfur is lower than QXRD mineralogy, when compared with XRF (e.g., Figure 2). The minerals which host these elements are important for environmental purposes (e.g., sulfur for acid generating sulfides / sulfates; as well as calcium and magnesium for acid neutralising carbonates).

4.3. Implications for AMD Hazard Classification

4.3.1. Maximum Potential Acidity

Four different methods of calculating MPA values are assessed:

1. Total Sulfur by XRF multiplied by 30.6, as per the conventional ABA approach.
2. The alunite concentration from HScan mineralogy.
3. The alunite concentration from HScan mineralogy with residual XRF sulfur for calculation of pyrite concentrations.
4. QXRD mineralogy.

MPA values derived from HScan mineralogy (Method 2) are systematically lower than those derived from the other methods. This is because HScan does not identify pyrite / marcasite in the current samples. If HScan mineralogy is to be used to calculate accurate MPA values, it must be supplemented with XRF sulfur. Therefore, method two is not discussed further.

Generally, the speciation of sulfur changes during weathering as sulfide minerals oxidise forming sulfate minerals. For the purpose of this study the pre-mining water table was used as a proxy for weathering. Samples derived from below the water table (BWT) generally have a larger proportion of their MPA bound in sulfide minerals. Whereas samples derived from (AWT) generally have a larger proportion of their MPA bound in sulfate minerals.

The MPA values derived by Methods 1, 3, and 4 are broadly similar for samples derived from BWT (see **Figure 3**). This is because samples from BWT generally have no or very low concentrations of alunite, and hence calculating MPA values using HScan with XRF total sulfur (Method 3) defaults to the assumption that all or most of the sulfur is bound in pyrite / marcasite (Method 1). Likewise, QXRD provides accurate determinations of sulfur bearing minerals and sulfur concentrations (see Section 3.3.1 and 3.3.2), and therefore provides similar MPA values to methods based on, or which utilise XRF total sulfur.

For samples derived from AWT, where secondary sulfate minerals are more abundant, there is greater variation between the results of different methods for calculating MPA values. Method 1, where no sulfur speciation is available returns, on average, the highest values. Both QXRD (Method 4) and HScan + XRF sulfur (Method 3) return lower (and likely more realistic) MPA values.

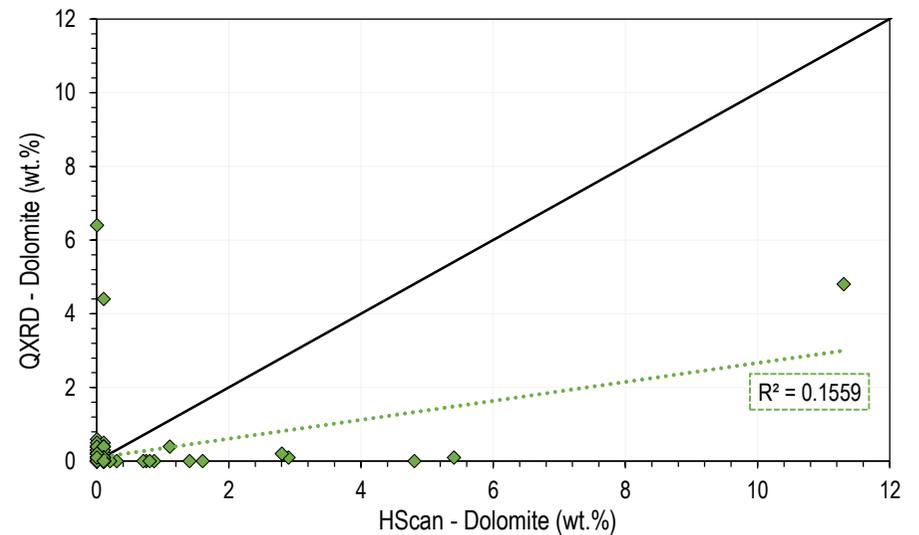
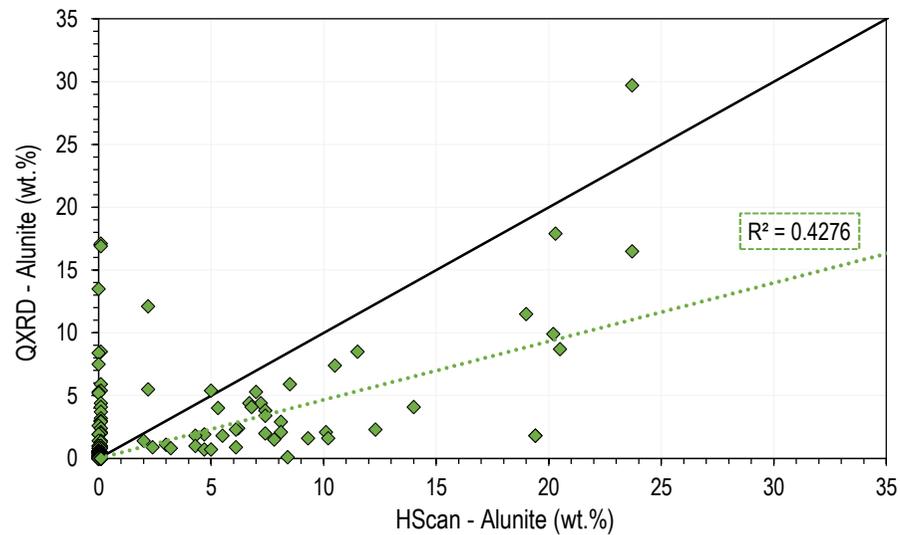
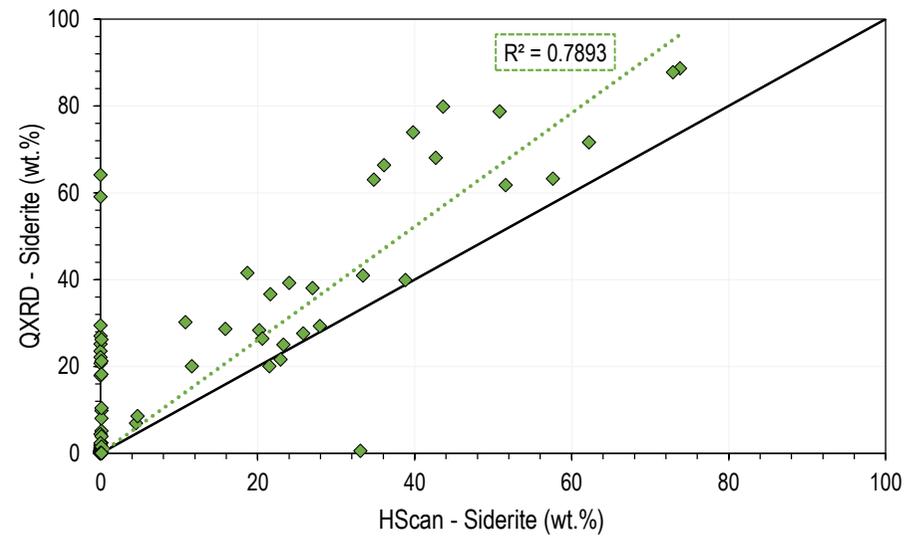
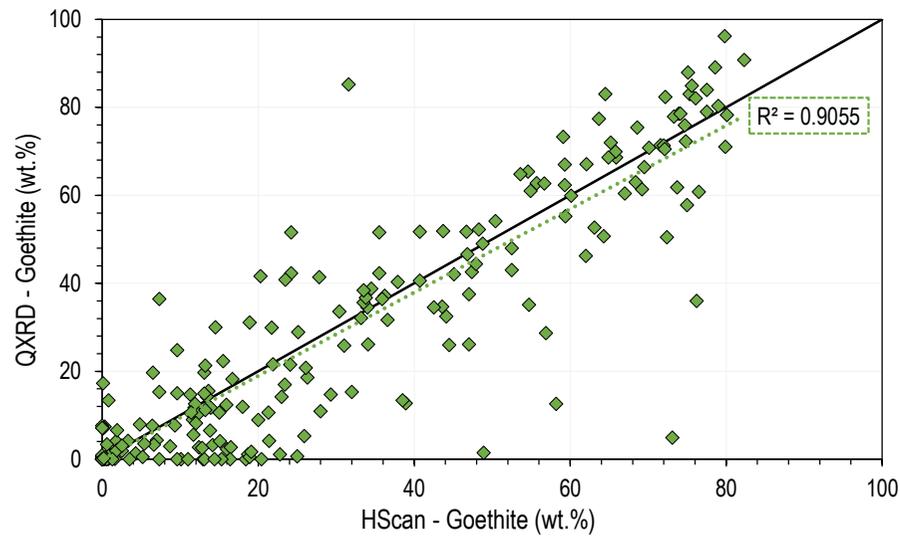


Figure 1 Comparison of mineral concentrations (Goethite, Siderite, Alunite, and Dolomite) measured by QXRD and HScan. The solid black line shows a 1:1 relationship.

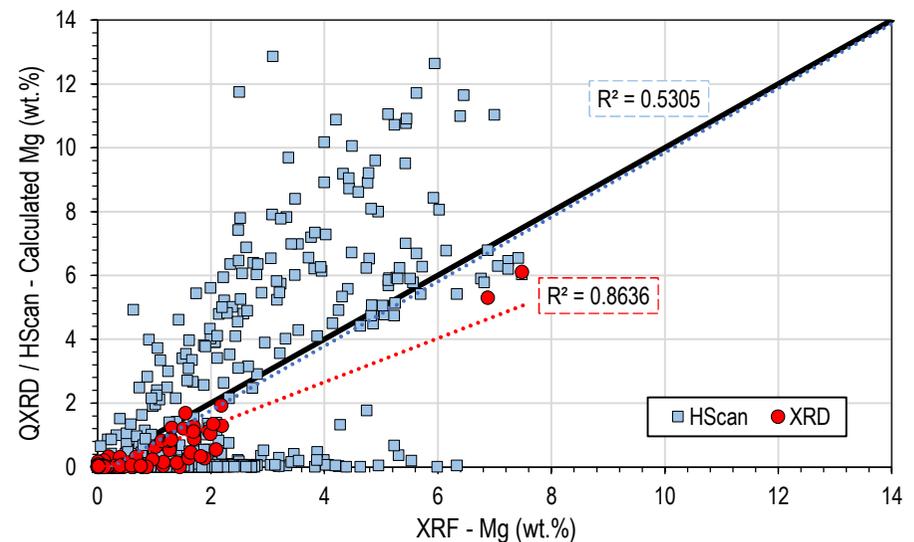
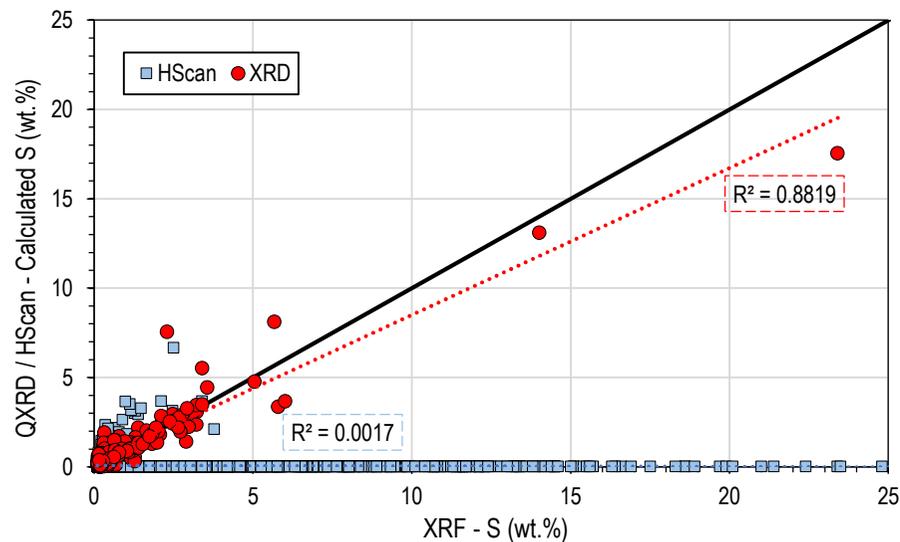
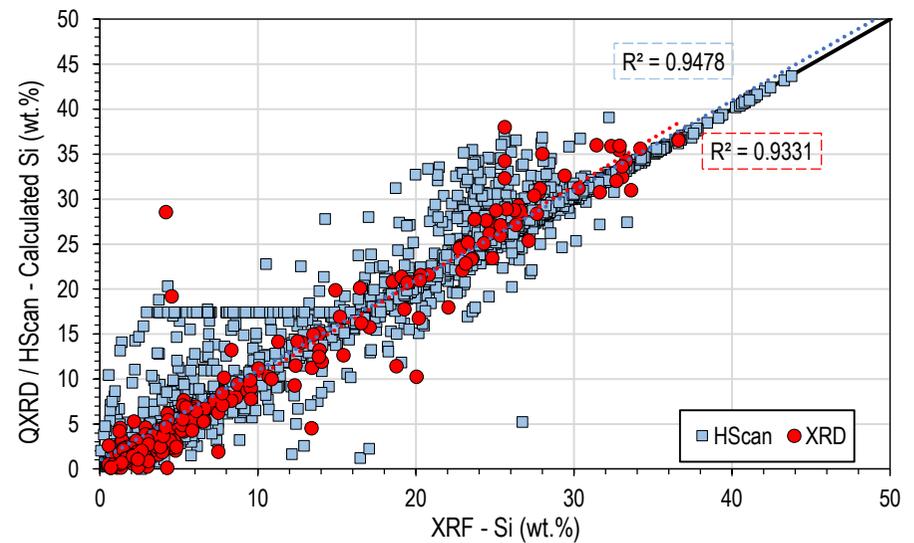
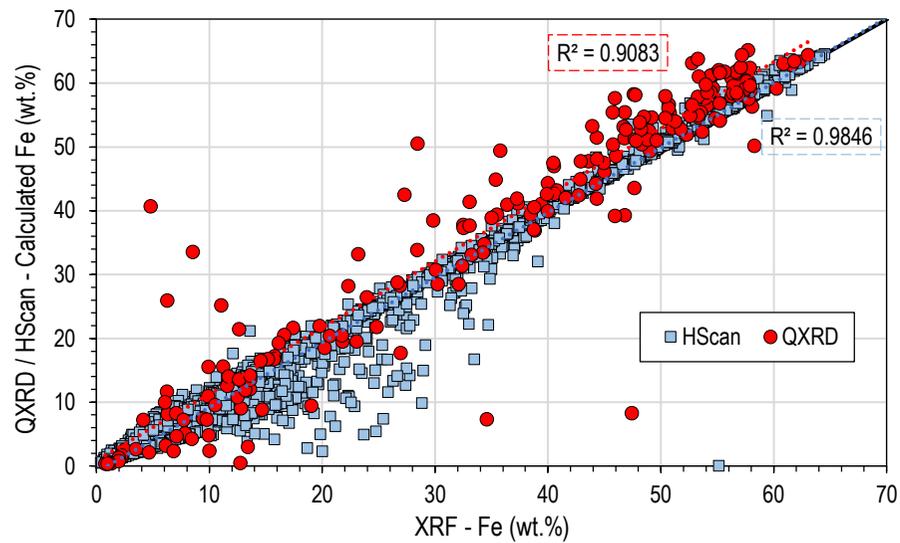


Figure 2 Relationship between elemental concentrations measured by XRF and elemental concentrations calculated from HScan and XQRD mineralogy.

4.3.2. Acid Neutralising Capacity

Four different methods of determining the ANC are assessed:

1. Conventional laboratory measured ANC via the AMIRA method (AMIRA, 2002).
2. BHP WAIO's ANC algorithm
3. ANC values calculated from HScan mineralogy.
4. ANC values calculated from QXRD mineralogy.

In general, ANC concentrations of the studied samples are low, where the 90th percentile ANC values for laboratory determinations (Method 1) are ~22 kg H₂SO₄ / tonne. The 90th percentile ANC values for mineralogical determinations (Methods 3 and 4) are slightly lower (< 6 kg H₂SO₄ / tonne).

At low concentrations there is limited correlation between the different methods of determining a samples ANC. Where ANC concentrations are less than ~10 kg H₂SO₄ / tonne, the laboratory measured values (Method 1) are systematically higher than other methods. Many of these samples with elevated ANC concentrations according to laboratory measurements, contain very low Ca / Mg concentrations (determined by XRF) which are inconsistent with the equivalent calcite or dolomite concentrations suggested by the laboratory determined ANC concentrations. Whereas, at the higher range of ANC concentrations, the correlation between laboratory measured ANC and ANC concentrations based on mineralogy (HScan or QXRD) improves.

BHP's ANC algorithm, on average, returns lower values than laboratory measured ANC determinations, and hence provides a conservative estimate of ANC.

ABCC data was only available for six samples, which had laboratory determined ANC concentrations ranging from below the detection limit to 58 kg H₂SO₄ / tonne. For all samples where ANC concentrations were above the detection limit, the ANC_{4.5} values are less than the ANC values, suggesting at least some acid neutralisation inefficiency. However, there is no clear relationship between the total ANC, and the ANC_{4.5} values, where the readily available ANC (ANC_{4.5}) represents between 26% and 84% of the total ANC.

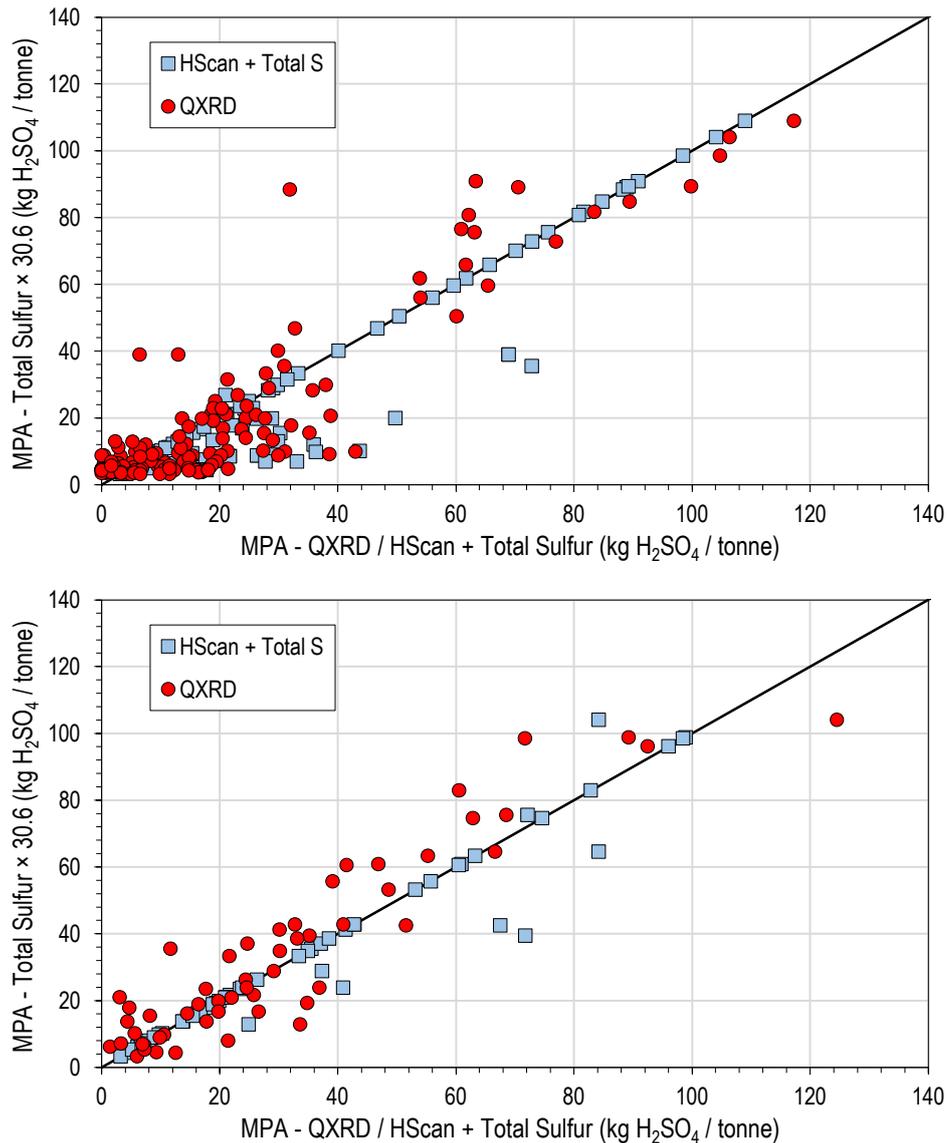


Figure 3 Relationship between MPA values calculated from QXRD mineralogy, HScan mineralogy supplemented with total sulfur (XRF) data, and conventional MPA values (i.e., Total Sulfur × 30.6). The top panel shows samples derived from AWT, and the bottom panel samples derived from BWT.

4.3.3. Net Acid Production Potential

NAPP values were calculated via 5 different methods (listed below):

1. BHP WAIO Classification System
2. Conventional static acid base accounting: $NAPP = MPA [Total\ sulfur \times 30.6] - ANC$ [Laboratory measured AMIRA method].
3. HScan mineralogy.
4. HScan mineralogy with Total Sulfur (XRF).
5. QXRD mineralogy.

The following discussion considers a subset of the studied samples (n = 80/214) for which laboratory measured ANC values were available. All samples (n = 80, 100%) were originally classified as PAF under BHP WAIO's AMD hazard classification system (i.e., Method 1).

When the conventional acid base accounting determinations are considered (i.e., Method 2), ~25% of samples (20 out of 80) are reclassified as NAF (Figure 4). The high number of samples reclassified as NAF compared with the other methods (see below) is likely due to the relative overestimation of ANC values by the AMIRA method when ANC concentrations are low (see Section 4.3.2).

According to QXRD mineralogy pyrite / marcasite is a significant contributor to the MPA of most samples, particularly those derived from BTW. However, HScan is unable to identify pyrite / marcasite in the studied samples. This results in underestimation of MPA and NAPP values in Method 3, and ~88% of samples (70 out of 80) being re-classified as NAF. As discussed above HScan mineralogy needs to be supplemented with XRF sulfur data in order to provide more accurate MPA / NAPP values and therefore improved AMD hazard classifications.

NAPP values calculated based on QXRD and 'HScan with Total Sulfur [XRF]' (i.e., Methods 4 and 5) result in similar numbers of samples being reclassified as NAF with ~13% and ~16% of samples, respectively. Therefore, sulfur speciation (e.g., QXRD), even if partial (i.e., HScan), provides more accurate MPA values and results in less samples being classified as PAF. Based on the data from this assessment, the current BHP classification system is conservative and results in over-management of waste.

It should be noted that the above statistics consider materials derived from both AWT and BWT, and it is known that the proportion of the MPA bound in sulfide minerals increases BWT. Therefore, the benefits of sulfur speciation data are largest for AWT materials, where a greater proportion of the MPA is bound in secondary sulfate minerals (which generate less acid per mol than pyrite). For example, when considering QXRD data, 18% of samples derived from AWT (i.e., 9/49) could be reclassified as NAF, whereas only 3% of samples derived from BWT (i.e., 1/31) could be reclassified as NAF.

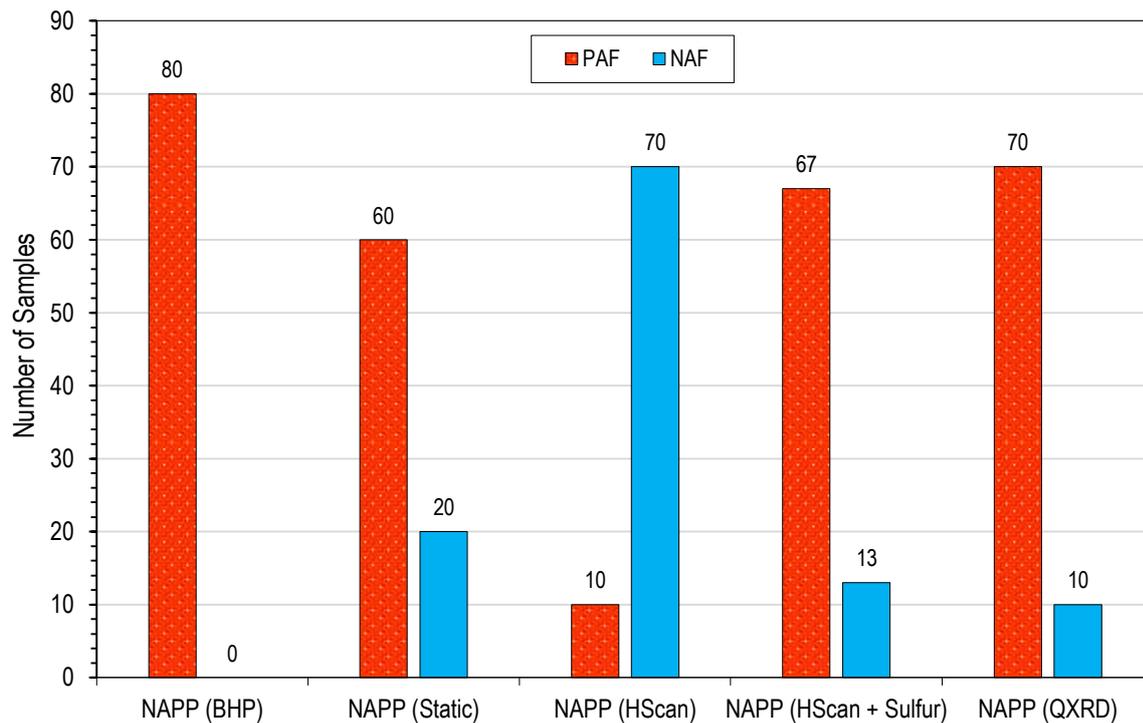


Figure 4 Comparison of NAPP values calculated by different methods (see main text for details).

CONCLUSIONS

In waste rock samples from across the Pilbara, QXRD identified a slightly larger range of minerals than Hyperspectral Scans (i.e., 28 – QXRD vs 21 - HScan). However, HScan provides additional information on non-crystalline and poorly crystalline materials (e.g., extent of kaolinite and goethite crystallinity, and organic matter concentrations). Both mineralogical techniques (HScan and QXRD) provide accurate quantification of the concentrations of key rock forming minerals (e.g., hematite, goethite, quartz, kaolinite, siderite) as well as major elements (e.g., Fe, Si, Al, LOI). Hence, BHP's existing and very large HScan mineralogy database provides valuable information for assessing ore materials, and assisting with mining, exploration, and geological interpretation.

However, the accuracy of mineralogical determinations (and therefore calculation of minor element concentrations) decreases as the concentration of the target mineral decreases, with QXRD providing more accurate determinations of minerals with low concentrations. This is significant as minerals of environmental significance in the Pilbara (e.g., acid neutralising carbonates) generally occur at low concentrations.

HScan only provides partial speciation of sulfur bearing minerals. HScan cannot detect pyrite / marcasite in the current samples. However, these sulfides are significant contributors to the MPA in samples from BTW, and therefore if HScan data are to be used to assist with validating AMD classifications and/or used as additional data for supporting AMD risk assessments, HScan mineralogy must be used in conjunction with XRF total sulfur concentrations.

Mineralogical determinations which provide full (QXRD) or partial (HScan) speciation of sulfur bearing phases can be used to improve the accuracy of MPA calculations, lower the resulting MPA values, and lower the amount of material that needs to be managed as PAF. Likewise, mineralogical determinations appear to provide more accurate estimates of ANC values, especially at low concentrations.

The BHP WAIO AMD classification, which is based on primary assay data and is embedded in all distribution models, has been shown to be conservative. Whilst QXRD likely provides the most accurate AMD classifications of the methods assessed, there is too little QXRD data to replace the current assay-based classification system used at BHP. However, the existing and large HScan mineralogy database in conjunction with XRF total sulfur data could be used for quantitative AMD hazard classifications to augment the current classification approach and/or in the long term replace it. Based on the current study this approach could reduce the amount of waste requiring selective management by approximately 10%.

Recalibration of HScan data with the growing QXRD database, and inclusion of these data across all distribution models, could improve the accuracy of HScan mineralogy and ultimately reduce the mass of waste rock requiring selective management.