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TECHNICAL MEMORANDUM

DATE	9 September 2022	**REF**	NSWDPE239607
TO	Ms Rose-Anne Hawkeswood – NSW Department of Planning and Environment	**REV**	0
FROM	Sophie Pape, Earth Systems Jeff Taylor, Earth Systems	**PROJECT**	Bowdens Silver Mine

DEVELOPMENT OF SAMPLING PROGRAM AND AMD RISK CLASSIFICATION SYSTEM

INTRODUCTION

The New South Wales Department of Planning and Environment (NSWDPE) has requested an independent review and advice in relation to acid and metalliferous drainage (AMD), water balance modelling and surface water management aspects of the proposed Bowden Silver Mine. Earth Systems were key authors of the Federal Government's Leading Practice handbooks on "*Managing Acid and Metalliferous Drainage*" (DITR, 2007) and "*Preventing Acid and Metalliferous Drainage*" (DIIS, 2016).

A Memorandum was prepared on 31 May 2022, summarising the key findings of Earth Systems' independent high level review with a focus on AMD / geochemical characterisation, impact assessment and related management aspects of the proposed mine development.

One of the key conclusions documented in Earth Systems (2022) was that the AMD risk classification was considered inappropriate for the Project, resulting in inaccurate predictions of potentially acid forming (PAF) and non acid forming (NAF) material tonnages. This will affect waste rock dump design and the availability of NAF materials for construction / rehabilitation requirements. The Memorandum is focussed on the issue of AMD risk classification. Once addressed, the next priority will be PAF waste rock management strategy development, informed by AMD risk classification and updated block modelling.

INITIAL AMD RISK CLASSIFICATION SYSTEM

As noted in Earth Systems (2022), a site-specific AMD risk classification system was developed by GCA (2020) based on 143 waste rock samples tested, to inform material types and management options. The AMD risk classification system proposed by GCA (2020) is outlined below:

- Weathered Zone
  - WZ1: Total S < 0.3% = initially sub-neutral (acidic pH) but evolving to NAF over time as “trace alunites” are leached with buffering from interactions with smectites.
  - WZ2: Total S > 0.3% = PAF (“>” assumed by Earth Systems to mean “≥”).
- Primary Zone
  - PZ1: Total S < 0.1% = NAF.
  - PZ2: Total S 0.1-0.3% within the northern section[1] of proposed main open cut pit = NAF.
  - PZ3: Total S > 0.3%; Total S 0.1-0.3% distant from the northern section of proposed main open cut pit = PAF.

The system recommended by GCA (2020) does not appear to have followed through correctly to the mine block model and waste rock schedule that form the basis of the waste rock dump design by Advisian (7 May 2020). A simpler classification was used by Advisian (2020a) – based only on a 0.3 wt.% Total S cutoff – which could result in some PAF material being inadvertently classified as NAF. Similarly, the EIS has used the 0.3 wt.% Total S cutoff (only) which ignores the potential for PAF waste rock in the 0.1-0.3 wt.% Total S range.

The sections below provide clarification of current concerns regarding the AMD risk classification system proposed by Bowdens Silver and outline additional work that would assist in addressing these concerns.

PROPOSED CHANGES TO AMD RISK CLASSIFICATION SYSTEM

The AMD risk classification system developed by GCA (2020) was based on detailed static geochemistry test work – including acid base accounting (ABA), net acid generation (NAG) suite, some sulfur and carbon speciation, and major/trace element geochemistry – albeit on a limited number of samples across the deposit. This included 143 waste rock samples in total, of which 16 samples were selected from the northern section of proposed main open cut pit. This sampling density corresponds to only 1 sample per 325,000 tonnes of waste rock. Around 20 samples were also subjected to semi-quantitative X-Ray Diffraction (XRD) test work to investigate sample mineralogy (GCA, 2020).

Extensive assay data (including sulfur, calcium and magnesium) and hyperspectral scanning data has been subsequently presented (Corkery, 2022), but no further detailed static geochemistry test work (ABA, NAG, QXRD[2], etc) has been undertaken since 2020 as a basis for updating the original AMD risk classification method (GCA, 2020). Assay data may become useful for AMD risk block model development, only if an

[1] Bowdens Silver indicated during discussion in August 2022 that the “northern section” has been subsequently well defined.

[2] Total Sulfur and ANC analyses are used to infer mineralogy and estimate acid base accounting (ABA) characteristics accordingly. QXRD data provide a more accurate understanding of sample mineralogy and hence can be used to calculate ABA parameters more accurately than total sulfur and ANC analyses.

appropriate AMD risk classification system can be verified for the Bowdens deposit from detailed and representative static geochemistry or QXRD data.

It is understood from recent discussions and new information (Corkery, 2022; GCA, 2022) that:

1. ***For waste rock in the northern section of the proposed main open cut pit (only)***, Bowdens Silver now proposes to use an algorithm developed by GCA (2022) to estimate a "residual" wt.%S and assign AMD risk classifications accordingly, based on assay data (sulfur, calcium and magnesium content). This method assumes that all calcium and magnesium is present in the form of acid neutralising minerals such as calcium carbonate and dolomite. However, there may be calcium- and magnesium-bearing minerals present that are not carbonates. XRD test work conducted to date includes only 3 samples in the northern section of the proposed main open cut pit, and is only semi-quantitative (mineral quantities are reported as either major, minor or trace).
2. ***For waste rock in the majority of the deposit, excluding the northern section of the main pit***, Bowdens Silver still appears to be using the simpler AMD risk classification system based only on a 0.3 wt.% Total S cutoff (Corkery, 2022). This remains at odds with the PZ3 definition originally recommended by GCA (2020).

With reference to Point 1 above:

- The proposed AMD risk classification method for waste rock in the northern section of the proposed main open cut pit (only), may be suitable if it can be verified with a sufficient number of QXRD analyses that all calcium and all magnesium are present in acid neutralising minerals only, and that other calcium and magnesium bearing minerals are absent. The minimum number of QXRD analyses required will depend on factors such as the total tonnage of material being represented, the number and type/complexity of lithologies present, weathering types, etc. and could be around 50-100 in total.
- If the proposed AMD risk classification method for waste rock in the northern section of the proposed main open cut pit (only) is verified to be accurate, a "residual" 0.00 wt.%S cutoff value for assigning PAF and NAF classifications would be more appropriate than the "residual" 0.10 wt.% S cutoff proposed by GCA (2022).
- As an alternative, or in combination with the QXRD test work recommended above, a substantial amount of additional drill core analysis for detailed static geochemistry parameters would be required to develop a reliable AMD risk classification system (eg. sulfur cutoff value) for waste rock in the northern section of the proposed main open cut pit. Several hundred representative samples (eg. DITR, 2007) may be required to develop an AMD risk classification system, if indeed this is possible for the Bowdens deposit. Further guidance on sampling is provided in Attachment A.

With reference to Point 2 above:

- Bowdens Silver acknowledges that PAF material dominates the majority of the deposit, excluding the northern section of the proposed main open cut pit, as indicated by spatial mapping (Corkery, 2022). Nevertheless, it remains unclear whether the use of a 0.3 wt.% S cutoff rather than the 0.1 wt.% S cutoff recommended by GCA (2020) has had much effect on overall PAF versus NAF waste rock tonnage estimates, ie. whether the estimated PAF tonnage would have been greater than 57% (reported in the EIS) if a 0.1 wt.% S cutoff was used for waste rock in the majority of the deposit (excluding the northern section of the main pit).

SUGGESTED WAY FORWARD

1. Conduct QXRD test work on sufficient representative samples from the northern section of the proposed main open cut pit to verify suitability of proposed "residual" wt.%S algorithm ***and/or*** conduct detailed static geochemistry test work including ABA, NAG suite, sulfur and carbon speciation, on at least 1 representative sample per 10,000 tonnes of waste rock material to determine whether a suitable AMD risk classification system can be developed for this part of the deposit.
2. Clarify the potential implications of the 0.1 wt.% S cutoff recommended by GCA (2020) for the majority of the deposit, excluding the northern section of the proposed main open cut pit, in terms of PAF and NAF waste rock tonnages.
3. Regardless of final estimates of PAF versus NAF waste rock tonnages, it is clear that the proportion of PAF waste rock will be substantial (eg. anywhere between 44% and >57% based on information reviewed to date). There remains considerable opportunity for improvement of the currently proposed AMD management strategy, supported by field or laboratory-based verification test work, in advance of project development. Leading practice approaches are provided in INAP (2020).
4. An additional benefit of the test work suggested above could be the potential to identify resources (eg. acid consuming or oxygen consuming NAF materials) and incorporate these into the site AMD risk classification system. A better understanding of the tonnages, proportion and scheduling of such materials may assist with waste rock dump strategy development.

REFERENCES

Advisian (2020a). *Preliminary Design of PAF Waste Rock Emplacement, Oxide Ore Stockpile and the Southern Barrier. Bowdens Silver Project.* Consultants report prepared by Advisian for Bowdens Silver Pty Ltd. 7 May 2020. 201010-00790—REP-002.

Advisian (2020b). *TSF and WRE Closure Cover Design. Bowdens Silver Project.* Consultants report prepared by Advisian for Bowdens Silver Pty Ltd. 7 May 2020. 201012-00683-SS-REP-0001.

Corkery (2022). *Waste Classification and Materials Balance*. Presentation slides prepared by R. W. Corkery & Co. Pty Ltd. 17 August 2022.

DIIS (2016). *Preventing Acid and Metalliferous Drainage*. Leading Practice for Sustainable Development Program for the Mining Industry. Australian Government. Department of Industry, Innovation and Science. September 2016.

DITR (2007). *Managing Acid and Metalliferous Drainage*. Leading Practice for Sustainable Development Program for the Mining Industry. Australian Government. Department of Industry, Tourism and Resources. February 2007.

Earth Systems (2022). *Independent Review – Acid and Metalliferous Drainage. Bowdens Silver Mine*. Technical memorandum prepared for the New South Wales Department of Planning and Environment (NSWDPE).

GCA (2020). Materials Characterisation Assessment. *Bowdens Silver Project.* Consultants report prepared by Graeme Campbell & Associates Pty Ltd for Bowdens Silver Pty Ltd. May 2020.

GCA (2022). *Bowdens Silver Project: Computational Approach Employing %S, %Ca and %Mg Assays in Geological Database for Mining-Stream Classification*. Memorandum prepared by Graeme Campbell & Associates Pty Ltd for Bowdens Silver Pty Ltd. 11 August 2022.

INAP (2020). *Rock Placement Strategies to Enhance Operational and Closure Performance of Mine Rock Stockpiles*. Prepared by Earth Systems and O'Kane Consultants for the International Network on Acid Prevention.

Attachment A

Extract from Leading Practice Handbook on Preventing Acid and Metalliferous Drainage

Sampling for Characterisation (DIIS, 2016; Section 4.2)

Overview (DIIS, 2016; Section 4.2.1)

Selecting samples and the methods used to collect them are critical tasks that need careful consideration at all stages of the project. As the project progresses from exploration through to feasibility, the range of samples tested should ultimately represent each type of material that will be excavated or exposed throughout the mine's life and after its closure. Enough samples should be obtained for each of the types of exposed material to determine the extent of significant variability in their material properties. Key mine material types to be sampled include waste rock, overburden, ore (run-of-mine and low-grade) and wall rock (open-cut/underground). While overburden might not contain much sulfide, it could still be geochemically enriched in metals and require specific management.

Each mine material type may consist of several different lithologies. In addition, each specific lithology can be weathered or oxidised to differing extents and, as this will influence the reactivity and AMD potential, the altered zones also need to be sampled and characterised. Even if sulfide concentrations are low or absent due to weathering processes, metalliferous drainage may still be an issue at some deposits. This highlights the importance of conducting geochemical sampling (and characterisation) of all material types.

Conducting representative sampling involves identifying the number and types of lithologies and the alteration and weathering sub-variants that constitute the bulk (>95%) of the total tonnage of materials to be excavated or exposed to oxidising conditions. Where possible, this sampling should span the full lateral and vertical extent of the ore deposit and associated waste and surrounding materials. It is important for expert advice to be sought at an early stage of project development to provide input into the design of the exploration drilling program and associated sampling for geochemical characterisation.

Representative samples of process/product/concentrate streams and tailings or other process waste streams should be obtained from metallurgical test work conducted during the feasibility and development stages of the project. Those samples are needed in addition to samples of ore, waste and surrounding materials to provide geochemical characterisation information for the tailings and product components of the AMD waste management system. Sulfide mineral concentrates can be very reactive and may require specific management where they are stockpiled (on site, during transport, or in intermediate storage at ports).

The numbers and type of samples selected will be site-specific and depend on the phase of the project (see Table 2 for guidance on sample numbers by project phase). Sufficient samples must be obtained to represent the variability/heterogeneity in each mine material as described above. Factors such as habit, grain size, structural defects, extent of alteration and dissemination or veining of reactive minerals (for example, sulfide minerals, carbonate minerals) must be addressed as part of the sample selection process to ensure that the full range of relevant properties is captured for each type of mine material.

Sample collection and handling requirements also need to consider the degree of weathering (for example, fresh, partially oxidised or fully oxidised) at the time of sampling, and implications for subsequent static or kinetic geochemical test work results. This is particularly important for aged drill core materials, weathered samples from brownfield or legacy sites, and sulfidic materials that are highly reactive and/or prone to spontaneous combustion. Ideally, samples from drill cores should be taken and tested as soon as possible after drilling. If that is not possible, the drill core should be stored under cover (for example, in a core shed) to minimise exposure to weathering processes until sampling and testing can occur. Drill chips should be stored in sealed heavy-duty plastic sample bags to minimise the potential for oxidation before testing.

In-place mine materials (DIIS, 2016; Section 4.2.2)

Although drilling and sampling tends to focus on ore zones in the exploration, pre-feasibility and feasibility phases, sufficient samples of potential wastes and exposed wall-rock material should also be collected to confirm that the future risk of AMD from those sources is not substantially underestimated. As the project develops, samples of waste rock and wall rock should be increasingly represented. This progressive development ensures that adequate data is available to produce a robust AMD block model and associated mine materials management schedule. Geostatistical analysis will ultimately be able to be used to inform and optimise the sampling strategy and to refine the block model. However, a sufficient number of samples representing the different lithologies, and the lateral distribution of properties within those lithologies, must initially be available before such analysis can be applied with a reasonable degree of confidence.

Sampling guidelines for static and kinetic geochemistry test work for initially in-place (that is, yet-to-be-mined) materials are summarised in [Box 1]. Indicative sampling frequencies are provided in Table 2 [of DIIS, 2016].

Samples collected for AMD assessment during operations are normally obtained from holes drilled for blasting or underground development. The inferred waste and ore boundaries are marked up using the geological block model on a map of the current bench plans for an open-cut mine (or on a map of the drive and stope development plans for an underground mine) and checked before and after blasting. The results from the characterisation of the blast hole samples are used to reconcile the geological model and AMD block model.

BOX 1: Sampling guidelines for in-place mine materials.

- *Multiple bulk samples, for both static and kinetic geochemical test work, are required to represent each lithology and weathering type from different parts of the deposit (that is, to ensure representative lateral and vertical variation).*
- *Continuous drillhole sampling should be completed where discrete samples collected for characterisation comprise a single lithology and weathering type, rather than spanning more than one type.*
- *Drillholes for sampling should be selected based on an even grid spacing and, in the case of metalliferous mines, should be sampled from surface (hanging wall) to the footwall of the ore body. Waste rock, ore and surrounding rock should be sampled. Diamond core provides the best source for sampling (since the intact material can be visually logged), followed by reverse circulation (RC) drill chips.[a] A similar sampling regime should be employed for coalmines, although sulfidic materials are often concentrated near and within coal seams, so the sampling intensity may be skewed towards those areas.*
- *Each bulk sample should be taken from a drillhole interval length sufficient to sample a single lithology (typically 0.5 m to 10 m), unless differential patterns of alteration indicate otherwise. Multiple lithologies should not be mixed. At coalmines, it is important to include specific coal seam roof, floor and major parting samples in the range of samples taken down a drillhole.*
- *Each bulk sample should comprise at least quarter core (minimum) extracted from the entire length of the selected drillhole interval to ensure that the sample is fully representative of that interval.*
- *Samples for geochemical test work should generally not be composited within each drillhole unless the subsamples used to produce the composite are obtained from the same lithology and drillhole interval. Sample compositing (for example, if a larger sample size is required for kinetic tests) can sometimes be undertaken after the results from initial geochemical screening tests have been acquired and interpreted,*

- *Each bulk sample should be crushed to <20 mm aggregate (or finer) to facilitate representative subsampling by 'splitting'. Representative subsamples cannot be achieved by grab sampling small masses of material from the bulk. Splitting using standard equipment (such as a rotary splitter or riffle splitter) and procedures produces representative subsamples of the required mass for static and/or kinetic geochemical analysis.*
- *For static geochemical test work, a minimum representative bulk subsample mass of 1 kg of aggregate is generally sufficient to submit to a laboratory. Additional sample preparation by laboratories includes further crushing to <2 mm or <4 mm, riffle splitting and pulverising to <100 µm, and the resultant pulp is subsampled for analysis.*
- *Bulk sample quantities are required for kinetic test work (Section 4.5). The samples can be around 2–5 kg for oxygen consumption test work, up to 35 kg for column leach test work, and up to 100 kg for oxygen diffusion test work.*
- *For kinetic geochemical test work, samples should ideally be prepared and tested in a manner that most closely simulates field conditions. However, for laboratory-based tests a smaller sample size means that waste rock needs to be crushed to ensure an adequate particle surface area and contact time with the leaching solution (typically deionised water or site rainwater). Bulk samples are typically crushed to pass a top size ranging from 5 mm to 40 mm, depending on the dimensions of the leaching apparatus. Tailings should be tested at the milled size that will be used for the process.*
- *Representative subsamples of the material used for kinetic geochemical test work (rather than similar/comparable mine material types) should be collected for static geochemical test work to assist in the interpretation of the findings.*

[a] In most metalliferous deposits, RC drilling or open-hole rotary air blast (RAB) drilling is commonly used to drill through the waste rock material, and coring using a diamond drill bit is used to sample the ore material. Thus, the bulk of the mine material available for sampling and testing for waste properties may be RC or RAB drill chips, with limited diamond core available for testing waste.