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Closure and reclamation of the Bouchard-Hébert mine site, Rouyn-Noranda, Québec, Canada

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Abstract

The Bouchard-Hébert mine is a closed zinc operation located approximately 30 km northeast of the city of Rouyn-Noranda in the Abitibi region of Québec, Canada. The mine operated from 1987 to 2002 and was closed in 2005. In 2021 approximately 50,000 m^3 of potentially acid generating (PAG) waste rock was relocated to the permanently flooded portion of the nearby open pit. This was done to both improve site aesthetics and reduce contaminant loads to groundwater downgradient and the site's water treatment system. The waste rock is partially oxidised and has generated substantial acidity and metal-laden seepage due to acid rock drainage/metal leaching (ARD/ML) since it was deposited. An additional 18,700 m^3 of waste rock was relocated to the pit in 2023 as part of ongoing reclamation activities.

Submerging PAG waste rock under water will eliminate future ARD/ML generation by these materials by preventing sulphide oxidation. This is best management practice for reactive, sulphide-bearing materials according to Mine Environment Neutral Drainage Program guidelines (MEND 2015) and other international guidelines, e.g. the Leading Practice Sustainable Development Program (LPSDP 2016). PAG waste rock relocated to the pit was amended with a neutralant (crushed limestone) to neutralise its existing acidity (titratable acidity plus jarosite acidity) content and thereby prevent the release of acidity and metals to groundwater once the waste rock is submerged. Waste rock that will not be submerged under water was amended with enough limestone to neutralise the total acidity content of the samples, i.e. acid generating potential and existing acidity. This paper describes how dosing rates were estimated and the process of mixing waste rock and limestone during relocation to the pit. The findings from recent sampling of the waste rock relocated in 2021 confirm that the jarosite in waste rock has decomposed.

Keywords: *mine closure, acid rock drainage, pit backfilling, limestone amendment*

1 Introduction

1.1 Site location and description

The Bouchard-Hébert mine is a closed zinc operation located approximately 30 km northeast of the city of Rouyn-Noranda in the Abitibi region of Québec, Canada. The mine operated from 1987 to 2002 and was closed in 2005. The site consists of the Industrial Area (Figure 1), where the concentrator (mill) and other infrastructure were located, the tailings storage facility (TSF) to the south of the Industrial Area, and several ponds related to the site's water treatment system. Ore was initially produced by mining the Main Lens using open pit mining methods, before the concentrator was constructed and underground mining methods were adopted during later stages of mining. Site closure and decommissioning involved removing the headframe,

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concentrator (mill) and other mine-related buildings, sealing the mine shaft at surface and placing a closure cover on the tailings contained in the TSF. Some potentially acid generating (PAG) waste rock was also relocated to the pit, which was not yet flooded at the time. However, approximately 100,000 m^3 of partially oxidised PAG and non-PAG waste rock remained at surface in the Industrial Area after closure works in 2005. Most of the buildings in the Industrial Area were underlain by this waste rock but not the concentrator, which was constructed directly upon bedrock.

1.2 Waste rock characteristics

Samples of waste rock in the Industrial Area were collected during test pitting investigations in 2019 and 2021 (see Figure 1 for test pit locations). Sample collection involved sieving and drying samples of bulk waste rock in the field to obtain a subsample for characterisation that was predominantly less than 19 mm in diameter. This is the size range considered of most concern with respect to future acid rock drainage/metal leaching (ARD/ML) generation. This size fraction, i.e. <19 mm, includes sand- to gravel-sized sulphidic material which tend to have higher reactivity and oxidation rates due to its greater surface-area-to-volume ratio compared to larger fragments. Qualitative assessment of particle size distribution during sampling indicated that this fine-grained fraction comprises the majority of the waste rock, with few cobbles or boulders present. Sulphide-bearing waste rock in the Industrial Area was classified as PAG or non-PAG material, based on the data produced by the standard acid-base accounting (ABA) suite. PAG waste rock is defined as any sulphide-bearing material with a neutralisation potential ratio (NPR) less than two, where NPR is calculated as neutralisation potential (NP) divided by acid generating potential (AP).

The ABA results indicate that a substantial proportion of the original pyrite content remains unoxidized, with the AP associated with unoxidised sulphide being comparable to the estimated quantity of existing acidity. The existing acidity content of waste rock consists of (i) titratable acidity and (ii) jarosite acidity, both of which are the products of pyrite oxidation occurring since waste rock was deposited at surface in the 1990s. Titratable acidity is the readily soluble portion of the total existing acidity and was estimated by direct titration using methods outlined by Jones (2015). The stored acidity associated with jarosite (a poorly soluble acidic secondary mineral) cannot be estimated by direct titration or simple leach extractions with water. The jarosite acidity content of waste rock samples collected from the Industrial Area (while the waste relocation project was being planned) was estimated from the jarosite content measured by X-ray diffraction (XRD). This involved calculating the moles of acidity associated with jarosite by stoichiometry and then converting the acidity to the calcium carbonate ($CaCO_3$) equivalence per tonne, i.e. kg $CaCO_3$ eq./t. Further details on methods are provided in Jones et al. (2020).

1.3 Restoration planning

The site restoration plan calls for waste rock from the Industrial Area to be relocated to the nearby open pit which is permanently flooded. In 2021 the site owner (Breakwater Resources Ltd.) elected to relocate PAG waste rock to the open pit as part of the restoration of the Industrial Area. This was done to both improve site aesthetics and to reduce contaminant loads to the site's water treatment system. Two phases of waste rock relocation were undertaken in 2021 and 2023, involving approximately 69,000 m^3 of PAG waste rock in total. Submerging PAG waste rock under water will eliminate future ARD/ML generation by these materials by preventing ongoing sulphide oxidation. This is best management practice for reactive, sulphide-bearing materials according to Mine Environment Neutral Drainage Program guidelines (MEND 2015) and other international guidelines, e.g. the Leading Practice Sustainable Development Program (LPSDP 2016). The addition of a neutralant to partially oxidised waste rock is also best management practice (see Section 1.4).

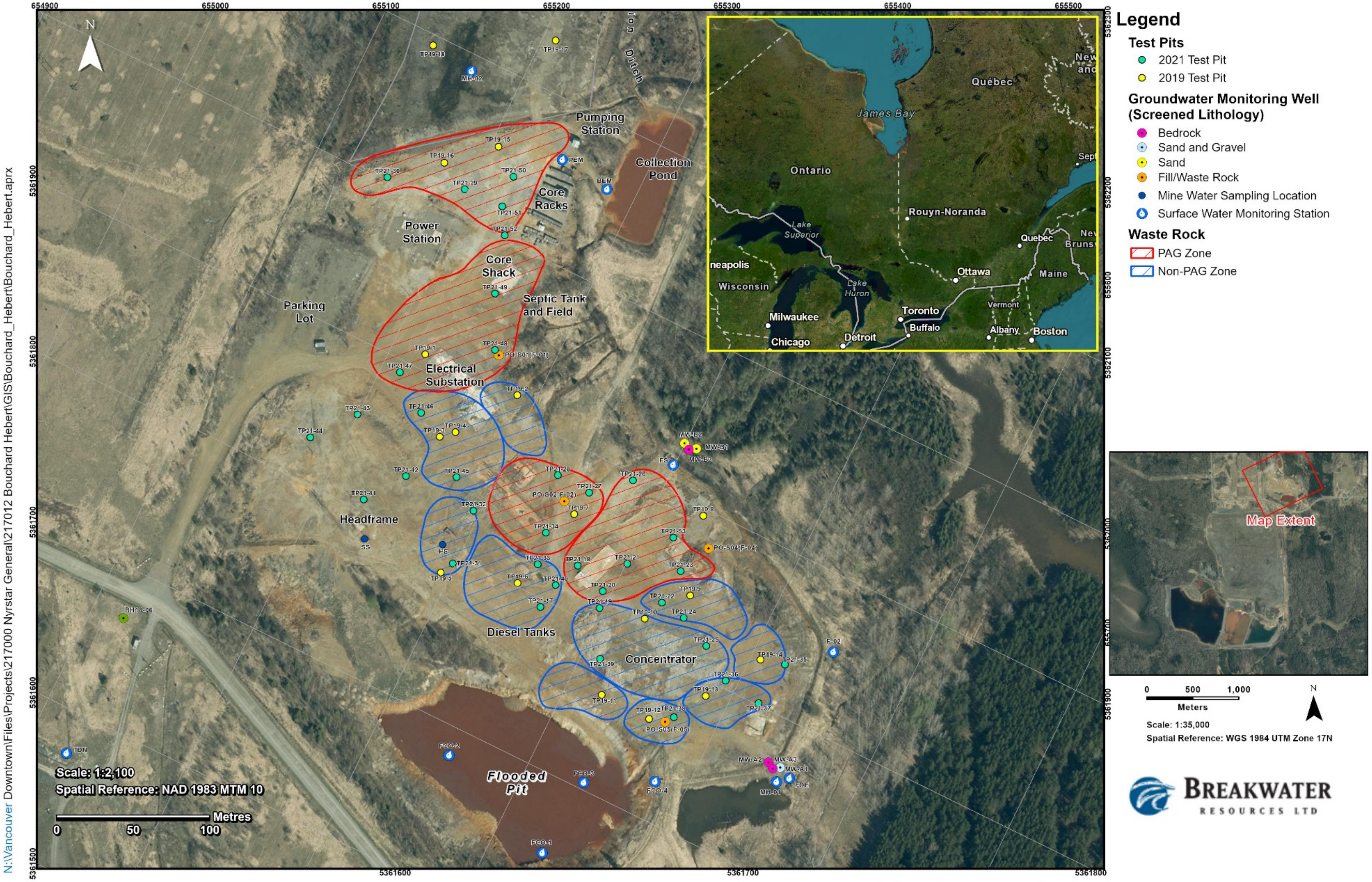

Figure 1 **Industrial Area, Bouchard-Hébert mine site. Inset shows the location of the city of Rouyn-Noranda, approximately 30 km from the mine site. Potentially acid generating (PAG) and non-PAG waste rock were identified in 14 areas of the Industrial Area as part of relocation planning**

1.4 Waste rock amendment with limestone

PAG waste rock relocated in 2021 was amended with finely crushed limestone to neutralise its existing acidity content and thereby prevent the release of acidity and metals once the waste rock is submerged. Further details are provided in Ferguson et al. (2021). The remaining PAG waste rock relocated in 2023 was amended with sufficient limestone to account for the total acidity (AP plus existing acidity). Whilst the waste rock relocated in 2023 will be submerged under water for most of the year, amendment for total acidity content was undertaken to address the potential risk of these materials being unsaturated for short periods of time during drought conditions or a long-term decrease in groundwater levels due to climate change.

Crushed, fine-grained limestone ($CaCO_3$) is the generally preferred neutralant for waste rock or soil amendment, given its geochemical characteristics and widespread availability. The limestone used at Bouchard-Hébert was 96% $CaCO_3$ and is a pale to medium grey colour with a powdery consistency (81% passing a 0.150 mm sieve). This fine-grained material was used as a key conclusion from previous work on the neutralisation of acidic material was that the neutralant needs to be fine-grained to achieve a successful outcome (Watling et al. 2010).

The dosing rate used for PAG waste rock relocated to the pit in 2021 was 26.5 kg $CaCO_3$ eq./t. This value represents the sum of the highest jarosite acidity content (9.6 kg $CaCO_3$ eq./t) in six samples of Zone 8 waste rock collected in 2020, and approximately 15 kg $CaCO_3$ eq./t of titratable acidity, which is the highest value observed in 10 samples from Zones 1, 7 and 8 waste rock. The dosing rate was corrected for the 96% purity of the limestone. Hence the dosing rate is very conservative due to: (1) the maximum existing acidity content values assumed; and (2) the derivation of existing acidity values from the low end of the particle size fraction (i.e. < 19 mm) of waste rock (which is the most reactive and hence contains the highest percentage by weight (wt.%) of existing acidity). A higher dosing rate was used in 2023 to also account for the additional (potential) acidity related to unoxidised sulphide minerals in waste rock, i.e. AP. As mentioned above, this was done to account for the risk of the waste rock becoming unsaturated during drought conditions.

1.5 2020 Field mixing trial

Field mixing trials were completed in 2020 to confirm that the crushed limestone and waste rock could be adequately mixed during the process of relocating these materials to the pit. Two trials were completed using approximately 12 m^3 of waste rock, which is the volume of waste rock that was to be transported by each dump truck load during waste relocation in 2021. One of the trials used a “ripper attachment” for an excavator (or dozer). This was found to be unsuccessful based on the results from post-mixing sampling validation. The other trial involved evaluating a “comb bucket” attachment for an excavator. The comb bucket allows limestone and waste rock to be “sifted” together by repeatedly scooping and dropping the mixture to achieve good mixing. The efficacy of the process was confirmed by the results from an intensive post-mixing sampling regime. It was therefore selected as the preferred mixing method for waste relocation in 2021.

2 Waste relocation and recent sampling

2.1 Waste relocation programs

2.1.1 Permits and approvals

The relocation of PAG waste rock to the pit in 2021 was carried out under a Certificate of Authorisation issued by the Québec Ministère de l’Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs (MELCCFP) in July 2021. The Certificate of Authorisation permitted the relocation of PAG waste rock to a maximum elevation of 289 m above sea level (m asl) in the pit. The 2021 backfill elevation is approximately 1.5 m below the lowest observed groundwater level near the pit since 2012, meaning any PAG waste rock placed at or below this elevation will be saturated year-round. The Certificate of Authorisation also permitted the relocation of non-PAG material and uncontaminated concrete rubble above 289 m asl, neither of which were relocated in 2021. The Phase II relocation undertaken in 2023 involved the relocation of additional waste rock, as well as concrete rubble, to the pit. The work was carried out under a second Certificate of Authorisation issued by the MELCCFP in May 2023.

2.1.2 Waste relocation timeline

Following dewatering of the pit waste rock, relocation commenced on 13 September and concluded on 14 October 2021.There were 24 working days during this five-week period. Figure 2 shows the complete sequence from Day 1 (dewatered pit before waste relocation commenced) to Day 24, when the backfill was completed. Waste rock relocation began on 13 June and concluded on 13 July 2023. Waste relocation commenced in Zone 2A and then the waste rock from Zone 2B was relocated (Figure 1). Waste rock was then relocated from Zones 3–6 and then Zones 9, 11, 12, 13 and 14.

2.1.3 Equipment used

Four excavators, six haul trucks, a front-end loader and a bulldozer were used during the project. One of the excavators worked exclusively in the pit to mix limestone and waste rock with a comb bucket attachment (Figure 3). The dozer worked in the pit to mix and spread limestone-amended waste rock and maintain the ramp that was used to access the pit. The other excavators mainly worked in the excavation areas, and the front-end loader weighed and added limestone to each truck before it drove into the pit.

2.1.4 Volumes relocated

Approximately 50,000 m^3 of PAG waste rock was relocated to the pit in 2021. This volume estimate is based on the calculated volume difference between the elevation surveys completed before and after the project. Trip logs maintained by the earthworks contractor suggest approximately 122,491 t of waste rock was relocated to the pit during the project, implying a waste rock density of around 2.4 t/m^3 in the pit. Waste rock was not placed above 289 m asl in 2021.

Approximately 18,700 m^3 of PAG waste rock was relocated to the pit in 2023. PAG waste rock was placed on top of previously relocated materials (2021) from an elevation of 289.0 m asl to 290.5 m asl. Concrete rubble and non-PAG materials were also relocated to the pit in 2023 and placed above elevation 290.5 m asl. Figures 4 and 5 show the Industrial Area in August 2023 after waste relocation was completed and the pit had been backfilled to an elevation of approximately 291.4 m asl.

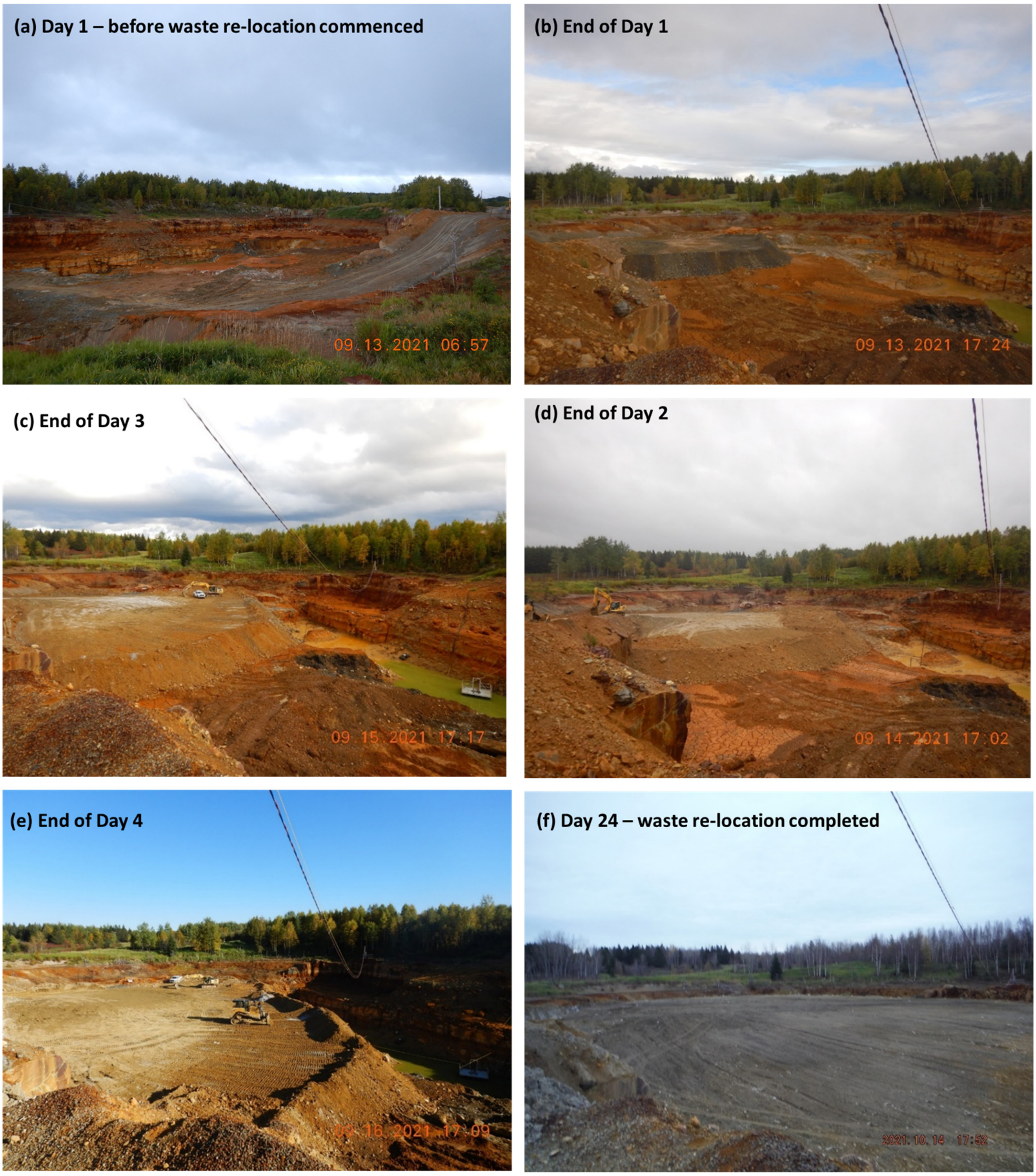

Figure 2 (a) The de-watered pit before waste relocation began in 2021; (b–f) Other photos taken at the end of days 1, 2, 3, and 4 and day 24, when waste relocation in 2021 was completed

Figure 3 Waste relocation in: (a) September 2021; (b) July 2023, when waste relocation commenced that year

Figure 4 Industrial Area, August 2023, after the relocation of waste rock and concrete rubble to the pit

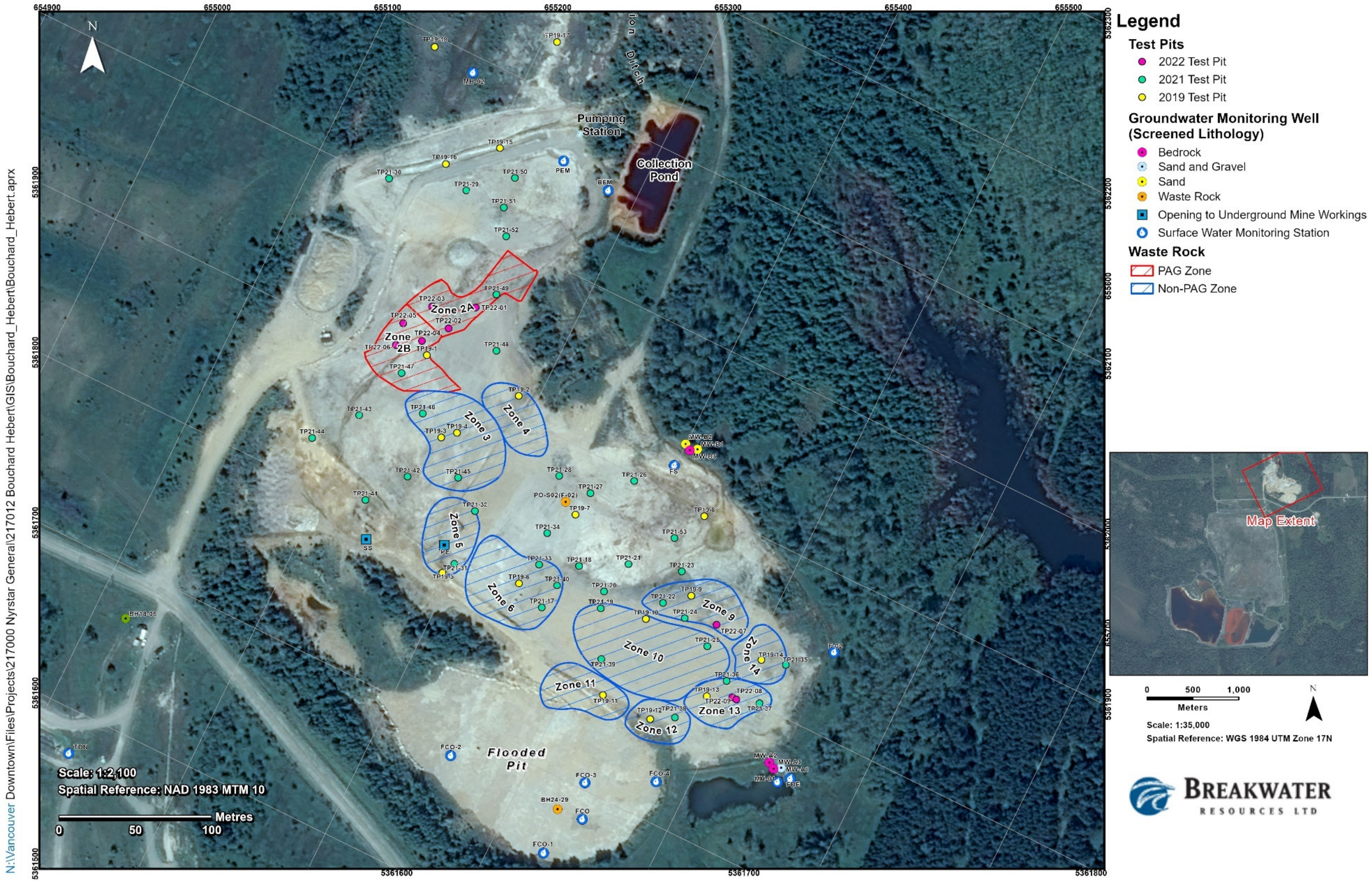

Figure 5 **Industrial Area, Bouchard-Hébert mine site. Waste zones are outlined on the map and test pitting locations are shown. The background image, from August 2023, shows the backfilled pit and the location of well BH24-29, which is screened in the waste rock relocated to the pit in 2021**

2.1.5 Quality control sampling program

Nine sampling campaigns were completed in the areas where waste rock was being excavated during the 2021 relocation program. Nine validation sampling campaigns were also completed in the areas where amended waste rock was being placed in the pit during the project. A key objective was to confirm that limestone and waste rock were being thoroughly mixed by the contractor using the comb bucket attachment for the excavator. QA/QC sampling involved collecting 10 samples from a 25 × 25 m area that was delineated at the bottom of the pit or in the reclamation working area. An equivalent rectilinear sampling area (5 × 125 m) was used when there was insufficient space for a square.

Four sampling campaigns were completed in the areas where waste rock was being excavated during the 2023 relocation program. Two campaigns were completed for Zone 2A, one for Zone 2B, and one for Zones 3 and 4. Three sampling campaigns were completed in the pit where waste rock was being placed during the project. The sampling procedures were the same as those used for samples collected from the excavation areas. Objectives were the same as in 2021 (see Section 3.1).

2.1.6 Neutralant (limestone) required

In 2021 a total of 4,380 t of crushed limestone was mixed with waste rock relocated to the pit. This implies a dosing rate of 35.7 kg limestone/t was achieved, assuming 122,691 t of waste rock was relocated. This is approximately 35% higher than the target dosing rate for waste rock (26.5 kg limestone/t), indicating that a higher dosing rate than required by the waste geochemistry had occurred. This was likely due to overestimation of the amount of waste rock hauled by each truck, which could not be determined due to the lack of a scale that could be used to weigh each loaded truck.

In 2023, 2,283 t of crushed limestone was delivered to the site during the program. The limestone was approximately 80% pulverised limestone “enhanced” with up to 20% hydrated lime; a product often used locally for agricultural purposes. The dosing rate for Zone 2A material was 123 kg limestone/t. A rate of 35 kg limestone/t was used for the other lower PAG waste rock relocated to the pit in 2023 (i.e. PAG rock from Zones 2B, 3, 4, 5 and 6).

3 Results and discussion

3.1 Waste rock relocation and amendment

The results from the nine sampling campaigns completed in the areas where waste rock was being excavated during the 2021 waste relocation project are compiled in Table 1. The lowest pH values, and highest electrical conductivity (EC), values were observed in Zones 1 and 2, and the portion of Zone 8 that was initially excavated. Waste rock from elsewhere in Zones 7 and 8 was characterised by a larger range of rinse values than the waste rock that was initially excavated, suggesting a mixture of waste rock with varying degrees of existing acidity and leachable solutes. In contrast, 96% of the samples collected from the pit backfill amended with limestone were characterised by a rinse pH value of 6.5 or higher (Table 1). This suggests the limestone and waste rock had been thoroughly mixed, which was further supported by ABA and shake flask extraction (SFE) results (see Table 1).

The ABA results for waste rock before and after amendment of the samples with limestone are summarised in Table 1. Each of the samples of limestone-amended waste rock collected from the pit was characterised by substantially higher NP (up to 116 kg $CaCO_3$/t) than unamended waste rock, which is often characterised by very low (or negative) NP values. The much higher NP values for limestone-amended waste rock suggest adequate mixing was achieved during relocation. This is supported by much higher pH and alkalinity values (from SFE) for the limestone-amended samples, which also supports good mixing. Dissolved zinc concentrations were also lower for the limestone-amended sample, due to the lower solubility of zinc at the circumneutral to slightly alkaline pH values.

Circumneutral pH and excess soluble alkalinity measured by the SFE leach confirm that the titratable acidity in the samples was neutralised within the duration of the SFE test. However, jarosite is a much slower-reacting component that can take months to years to fully react under these pH conditions. Critically, the amount of residual available NP in the samples significantly exceeds the jarosite acidity (30–40 kg/t) present. Hence there is high confidence that not only has the requisite dosing been achieved but that the limestone has been mixed sufficiently well to distribute the neutralant through the bulk of the waste rock.

In 2023 waste rock was placed on top of the waste rock relocated in 2021. Each of the waste rock samples collected in 2023 from Zone 2A had a rinse pH of less than 3.5, with an average of 2.6 and 3.1 for the first and second sampling campaigns, respectively (Table 2). Excavated samples from Zones 2B, 3 and 4, and waste material stockpiled outside the pit, show a wider range of rinse pH, with an average over 1 unit higher than that of Zone 2A. Rinse EC is also noticeably higher for the first sampling campaign from Zone 2A, suggesting a higher solute (and acidity) content. The rest of the excavated waste rock is characterised by lower rinse EC values, i.e. 859 to 1,594 µS/cm, which are consistent with previously reported data for Zone 2 samples.

Rinse pH values for amended waste rock (i.e. 1-Pit, 2-Pit and 3-Pit) placed in the pit are much higher than the rinse pH values for the excavated material, due to the reaction of the limestone with the existing soluble acidity. The average rinse pH value (n = 23) is pH 11.4 and the median value is 12.0, with only two samples having a rinse pH value of less than 7.7. These rinse pH values (for 91% of the samples) indicate that the waste rock and limestone were adequately mixed during relocation. The high pH values (> pH 10) reflect the hydrated lime that was part of the limestone mix and are not an environmental concern.

ABA results indicate that the samples of PAG waste rock are acid-generating, with each sample also characterised by significant existing acidity. NP values for excavated waste rock are often negative, which implies acidity is released from the sample. This is an artifact of the titration method used to estimate NP and suggests the materials are already substantially oxidised, with almost no capacity to neutralise produced acidity. NP values for limestone-amended waste rock are much higher than excavated waste rock due to the limestone that was added during relocation. The estimated total and existing acidity content of the waste rock relocated in 2023 (Table 3) indicates that the amount of added NP, averaging 92 kg $CaCO_3$ eq./t, greatly exceeds the total existing acidity, which has a maximum value of 32 kg $CaCO_3$ eq./t.

3.2 Recent (2024) sampling of relocated waste rock

In 2024, three waste rock samples were collected from the backfilled pit (BH24-29, Figure 5) at depth intervals of 2–3, 4–4.5 and 5.5–6 m below ground surface during a hydrogeological drilling investigation. These samples have an alkaline pH with residual NP values ranging from 14 to 45 kg $CaCO_3$ eq./t, indicating that there is still an excess of crushed limestone in the samples. XRD analysis shows that jarosite is not detected in the samples. The waste rock originally contained up to 3.6 wt.% jarosite when relocated to the pit. The fact that none was found in the recovered samples indicates that it has decomposed since the relocation and amendment (a maximum of 974 days) of the PAG waste rock. Assuming an average starting jarosite content of 0.8 wt.% for material relocated since September 2021, this would correspond to a jarosite decomposition rate of 8.2 mg/kg/day.

Table 1 2021 acid-base accounting and shake flask extraction (SFE) results for excavated (unamended) waste rock and amended waste rock in the pit

Sample ID	Rinse data		Acid-base accounting results										SFE results (3:1 L/S ratio)		
	pH	EC µS/cm	Paste pH	$S_{total, LECO}$ wt.%	$S_{sulphate}$ wt.%	$S_{jarosite, XRD}$ wt.%	$S_{sulphide}$ wt.%	AP kg $CaCO_3$ eq./t	NP kg $CaCO_3$ eq./t	NNP kg $CaCO_3$ eq./t	NPR	Class	pH	$Alkalinity_{titration}$ mg $CaCO_3$/L	Zn-d mg/L
Unamended waste rock (excavated from Zones 1, 2, 6, 7 and 8)															
1-Zone 1-4	2.6	2,530	3.5	4.6	1	0.2	3.5	110	–9	–119	–0.1	PAG	–	–	–
1-Zone 1-6	2.7	2,600	3.6	7.5	0.9	0.1	6.4	201	–12	–213	–0.1	PAG	–	–	–
2-Zone 8-2	2.4	2,790	3	5.2	2	0.1	3	94	–18	–112	–0.2	PAG	–	–	–
2-Zone 8-8	2.1	6,780	4.2	33	1.4	0	31	973	–13	–986	–0.01	PAG	–	–	–
3-Zone 8-5	2.3	3,320	3.8	2.1	1.8	0.1	0.1	4	–10	–13	–3	PAG	–	–	–
4-Zone 8-2	7.5	1,542	7.7	0.4	0.2	0	0.2	8	22	15	3	PAG	–	–	–
4-Zone 8-6	2.4	3,940	3.8	2.3	2.2	0.1	0	0	–10	–10	0.1	PAG	–	–	–
5-Zone 8-7	6.9	464	8.1	0.7	0.03	0	0.7	21	34	14	2	PAG	–	–	–
5-Zone 8-9	2.6	2,390	3.7	3.2	1.2	0.1	1.9	60	–12	–72	–0.2	PAG	–	–	–
6-Zone 8-5	6.8	1,935	7.5	1	0.5	0.04	0.5	16	19	3	1	PAG	–	–	–
6-Zone 8-8	2.2	6,090	3.6	2	2	0.07	0	0	–18	–18	0.1	PAG	–	–	–
6-Zone 8-10	2.5	3,120	3.5	3.6	3.7	0.1	0	0	–15	–15	0.1	PAG	–	–	–
7-Zone 7-1	7.2	1,049	6.7	0.2	0.1	0	0.05	2	9	7	5	PAG	–	–	–
7-Zone 7-4	2.6	1,400	3.4	0.9	0.9	0.2	0	0	–18	–18	0.1	PAG	–	–	–
7-Zone 7-8	6	261	6.9	0.1	0.1	0.04	0	0	3	3	0.1	PAG	–	–	–
9-Zone 2-1	2.6	5,010	3.4	1.8	1.2	0.1	0.5	16	–14	–30	–0.9	PAG	–	–	–
9-Zone 2-7	2.7	3,550	3.5	6.3	0.7	0.08	5.6	174	–9	–183	–0.1	PAG	–	–	–
10-Zone 2-6	2.8	2,880	3.6	5.3	0.9	0.3	4.1	129	–10	–139	–0.1	PAG	–	–	–
Aglime-amended waste rock (placed in the pit)															
1-Pit-2	6.7	2,170	7.9	0.9	0.4	–	0.5	15	51	36	3	PAG	7.5	28	0.03
1-Pit-8	6.7	1,660	8.1	0.6	0.2	–	0.4	12	116	104	10	PAG	7.7	31	0.2
2-Pit-3	7.7	935	8.2	2.1	0.8	–	1.4	43	41	–2	0.9	PAG	7.6	30	0.02
2-Pit-8	7.5	1,031	7.6	2.8	1.1	–	1.7	54	34	–20	0.6	PAG	7.6	32	0.02
3-Pit-10	7.5	422	7.6	4.7	0.9	–	3.8	118	27	–91	0.2	PAG	7.7	34	0.01
3-Pit-4	7.3	675	7.6	5.7	1.3	–	4.5	139	40	–99	0.3	PAG	7.7	38	0.07
4-Pit-3	7.5	1,031	7.4	3.4	0.8	–	2.5	79	41	–38	0.5	PAG	7.7	39	0.01
4-Pit-7	7.1	985	7.7	3.9	0.7	–	3.3	102	34	-68	0.3	PAG	7.7	36	0.004
5-Pit-2	7.5	2,170	7.2	2.9	1.8	–	1.2	37	17	–21	0.4	PAG	7.6	51	0.002
5-Pit-8	7.4	2,120	7.6	3.2	1.5	–	1.7	53	88	35	2	PAG	7.7	44	0.002
6-Pit-4	8	2,110	7.6	1.4	0.8	–	0.6	19	54	35	3	PAG	7.6	38	0.002
7-Pit-7	7.6	2,150	7.7	1.5	0.9	–	0.7	21	59	38	3	PAG	7.6	36	0.002
8-Pit-1	7.3	2,280	7.3	7	0.9	–	6.1	189	46	–143	0.2	PAG	7.7	46	0.01
8-Pit-10	7.2	2,250	7.6	3	0.7	–	2.3	71	202	131	3	PAG	7.7	57	0.01
9-Pit-4	6.7	1,511	7.4	2	0.5	–	1.6	49	50	0.7	1	PAG	7.7	50	0.01
9-Pit-8	7.3	360	7.9	0.1	0.03	–	0.07	2	36	34	17	PAG	7.9	47	<0.002

Table 2 2023 acid-base accounting results for excavated (unamended) waste rock and amended waste rock in the pit

Sample ID	Rinse data		Mineralogy by XRD			Acid-base accounting results									
	pH	EC	Pyrite	Gypsum	Jarosite	Paste pH	$S_{tot.}$	S_{SO4}	$S_{jar.}$	S_{S2-}	AP	NP	NNP	NPR	Class
		µS/cm	wt.%	wt.%	wt.%		%	%	%	%	kg $CaCO_3$ eq./t				
Unamended waste rock from excavated area															
1-Zone 2A-2	2.4	4,670	16.9	4.3	3.3	2.8	5	0.8	0.4	9	282	–16	–298	–0.1	PAG
2-Zone 2A-6	2.8	1,424	1.6	1.6	1.9	2.7	2.3	0.3	0.2	0.8	27	–14	–41	–0.5	PAG
1-Zone 2B-3	5.7	461	–	2.5	–	5.5	0.1	0.5	-	0	0	2.7	3	>>2	Non-PAG
1-Zone 2B-7	3.9	2,440	0.1	0.8	0.3	3.9	0.4	0.2	0.04	0.1	1.8	–6	–8	–3.3	PAG
1-Zone 3 & 4-3	2.7	2,080	1.2	2.4	1.6	3	1.2	0.4	0.2	0.6	20	–	–24	–0.2	PAG
Amended waste rock from the pit															
1-Pit-3 (from Zone 2A)	12	4,390	–	–	–	–	–	–	–	–	–	91	–	–	–
1-Pit-5 (from Zone 2A)	12.3	7,810	–	–	–	–	–	–	–	–	–	165	–	–	–
2-Pit-3 (from Zone 2B)	12.3	7,350	–	–	–	–	–	–	–	–	–	125	–	–	–
2-Pit-4 (from Zone 2B)	11.3	1,036	–	–	–	–	–	–	–	–	–	27	–	–	–
3-Pit-2 (from Zones 3 & 4)	11.8	2,410	–	–	–	–	–	–	–	–	–	54	–	–	–

Table 3 2023 acidity content of excavated (unamended) waste rock and amended waste rock in the pit

Sample ID	S_{S2-}	NP	Estimated acidity content				
			Titratable acidity (to pH 7)	Jarosite acidity	AP	Total existing acidity	Total acidity
	%	kg CaCO3 eq./t	kg CaCO3 eq./t				
Unamended waste rock from excavated area							
1-Zone 2A-2	9	–16	22	10	282	32	314
2-Zone 2A-6	0.8	–14	12	5.6	27	18	44
1-Zone 2B-3	0	2.7	0.7	0	0	1	0.7
1-Zone 2B-7	0.1	–6	6.6	0.9	1.8	7	9
1-Zone 3 & 4-3	0.6	–4.9	10	4.9	20	15	34
Amended waste rock from the pit							
1-Pit-3 (from Zone 2A)	–	91	–	–	–	–	–
1-Pit-5 (from Zone 2A)	–	165	–	–	–	–	–
2-Pit-3 (from Zone 2B)	–	125	–	–	–	–	–
2-Pit-4 (from Zone 2B)	–	27	–	–	–	–	–
3-Pit-2 (from Zones 3 & 4)	–	54	–	–	–	–	–

4 Conclusion

Since 2021 approximately 70,000 m^3 of partially oxidised waste rock has been relocated to the pit in the Industrial Area at Bouchard-Hébert mine. This has eliminated a major surface source of acid rock drainage/metal leaching to the site's water treatment system. Waste rock relocated in 2021 was amended with enough neutralant (limestone) to neutralise the existing acidity content of waste rock, as this waste rock is submerged under water year-round, thereby preventing future sulphide oxidation.

Sampling in 2024 of waste rock relocated to the pit in 2021 showed an alkaline pH with residual NP values ranging from 14 to 45 kg $CaCO_3$ eq./t, indicating that there is still an excess of crushed limestone in the samples. No jarosite was detected, indicating complete decomposition within the approximately three years since amendment and relocation in September 2021. The absence of jarosite and the presence of residual NP confirm that the amount of crushed limestone that was added was more than sufficient to neutralise existing acidity.

Waste rock relocated in 2023 was amended with enough neutralant to account for both acid generating potential and existing acidity. The higher dosing rate was used to ensure that any future acidity released from waste rock by sulphide oxidation would be neutralised, should the materials become unsaturated for short periods of time. Approximately 10,000 m^3 of potentially acid generating waste rock remains to be relocated to the pit as part of future site restoration. This material will also be amended with a dosing rate that accounts for total acidity as it will not be submerged underwater.

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