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MEMORANDUM

To: Harry Bronozian, MS; Chemical/Environmental Engineer
cc: André Sobolewski, PhD, Clear Coast Consulting; Andrea Gerson, PhD and Roger Smart, PhD; Blue Minerals Consultancy
From: Ann Maest, PhD; Buka Environmental
Date: 30 October 2017
Re: Evaluation of Geochemical Characterization Results and Proposed Additional Studies for the Amulsar Project, Armenia

1. Main summary points

Lydian did not follow accepted procedures for geochemical characterization of mined materials. Errors or omissions include: not identifying geochemical test units for wastes; using too few samples relative to the volume of rock mined; not using samples that represent the full range of acid-generating or contaminant leaching behaviors; prematurely ending kinetic tests before they reached steady-state or maximum contaminant concentrations or steady-state pH values; using inappropriate short-term leach tests; and not testing mitigation measures claimed to prevent or mitigate the formation and transport of acid mine waters. Considering the available data and these errors or omissions, we disagree with the conclusion of Lydian's independent reviewers for the Amulsar Project, Knight Piésold, that the characterization program was adequate and with Lydian's claim that spent ore and Upper Volcanic wastes will be non-acid-generating. The preponderance of the rocks at Amulsar are potentially acid-generating, and little to no neutralizing rock exists in the deposit.

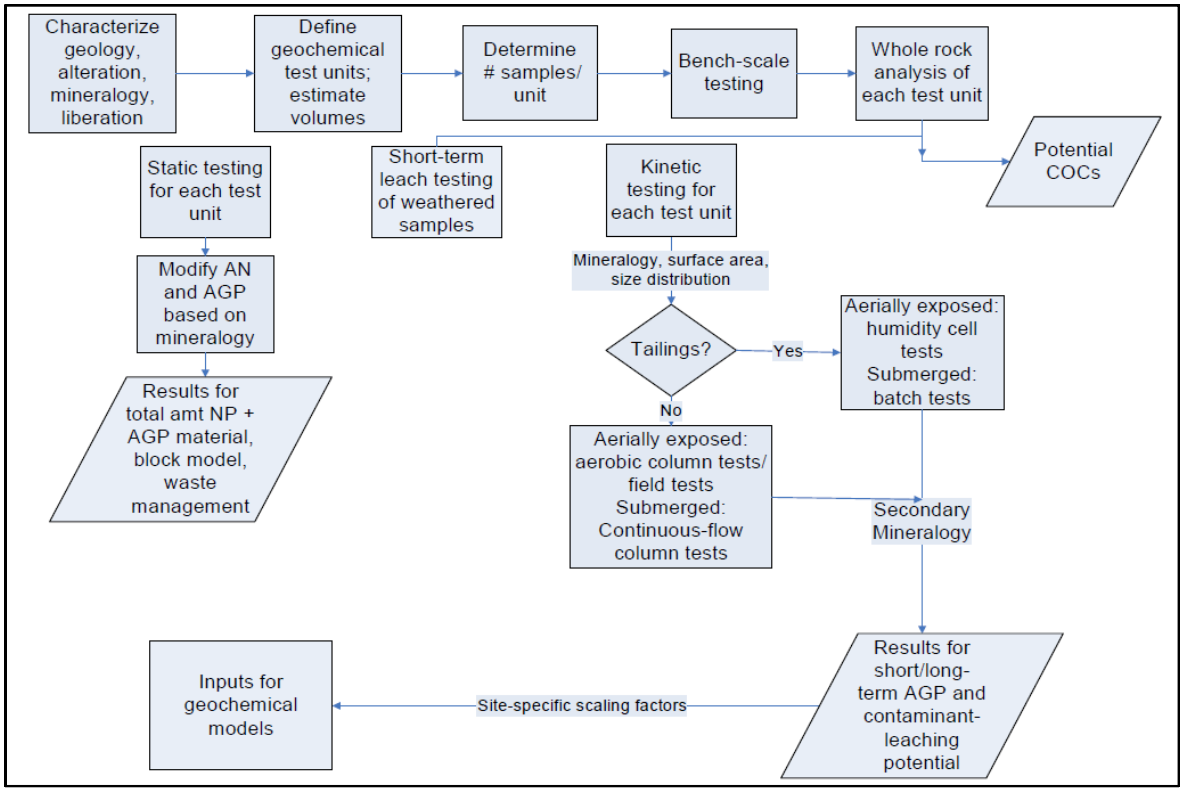
2. General approach for geochemical characterization of mined materials: approach used vs good practice, and additional testing proposed by Lydian

Figure 1 shows a generalized approach for conducting a geochemical characterization program for mined materials. Approaches vary, but identifying the geochemical test units[1] is one of the first steps in a geochemical characterization program (see, for example, Maest et al., 2005; GARD Guide, Section 4.3.2.1; Price, 2009; Parbhakar-Fox and Lottermoser, 2015). This approach is taken because each geochemical unit will contribute uniquely and differently to the overall contaminant load generated at the site. Results from these geochemical test units can then be used for water quality predictions (GARD Guide, Section 5.3.3, Figure 5-2). This step was omitted by Lydian and Global Resource Engineering, Ltd (ESIA, 2015, Appendix 4.6.2). Instead, the only units tested for mine waste

[1] Mined materials with similar textural, mineralogical, alteration, and chemical characteristics from which a similar acid forming and metal leaching potential can be predicted for ores and wastes.

were Upper Volcanics (UV) and Lower Volcanics (LV). Multiple alteration types and mineralogic assemblages have been identified by Lydian (2017; see, for example, Section 7.2.3, Figure 7.4, and Section 8.0), and these alteration types should be used to identify different geochemical testing units.

Figure 1. Generalized geochemical characterization approach.



Source: Maest et al., 2005.

The next step is to determine the number of samples that should be subjected to geochemical testing for each test unit. Generally, this is based on the volume of rock mined for each geochemical unit. The number of samples refers to the number of different samples collected throughout the deposit and potential waste units rather than the number of geochemical tests conducted. Ideally, each sample would be subjected to a series of geochemical tests.

Lydian conducted a total of 143 acid-base accounting (ABA) measurements and 90 bulk chemistry/whole rock analyses on all waste samples; these appear to be on different samples because the sample identifiers are different (ESIA, 2015, Appendix 4.6.2, Appendix Tables A-1 (ABA) and B-1 (whole rock)). The maximum number of samples collected and analyzed for any given test was 143 for ABA testing (59 for UV samples and 84 for LV samples). Geochemical test units should be identified, and a given sample should be subjected to the full suite of geochemical tests (Maest et al., 2005); numbers of samples can decrease going from ABA and whole rock testing to detailed mineralogy and short-term and kinetic testing (Parbhakar-Fox and Lottermoser, 2015).

Table 1 presents the amount of Amulsar waste and ore and the maximum number of samples analyzed for any given geochemical test (in this case, ABA testing). Figure 2 shows the number of samples for Amulsar LV and UV wastes and ore compared to recommended sample numbers from

Parbhakar-Fox and Dominy (2017). The comparison shows that the number of Amulsar samples is substantially below either recommended sampling framework, especially for Amulsar ore.

The plan for additional geochemical characterization does not fill the gaps in the geoenvironmental sampling and analysis program that are needed to evaluate the acid-generation and metal-leaching potential of Amulsar mined materials. Lydian's recommendations for further geochemical characterization are (Lydian, 2017, Section 26.5):

- "Additional studies are required to determine the residual nitrate in barren rock and spent ore.
- On site kinetic geochemical characterization tests are recommended to verify that waste from Amulsar is naturally-resistant to ferric iron oxidation ARD reactions…
- The ARD management plan requires evapotranspiration covers (ET Cover) on the BRSF and HLF. An ET Cover test cell is required to verify the performance of the designed ET Cover under site conditions."

Table 1: Amount of Amulsar waste and ore, and maximum number of samples analyzed for a given geochemical test.

	Amount Material (million tonnes)	Maximum # of geochemical samples analyzed for any given test
UV waste	136	59
LV waste	86.9	84
Total waste	222.9	143
Tig/Art ore	79	7
Erato ore	24	6
Total ore	103	13

Sources: Lydian (2017); ESIA, 2015, Appendix 4.6.2, Appendix Tables. UV = Upper Volcanics; LV = Lower Volcanics; Tig/Art = Tigranes/Artavazdes pit.

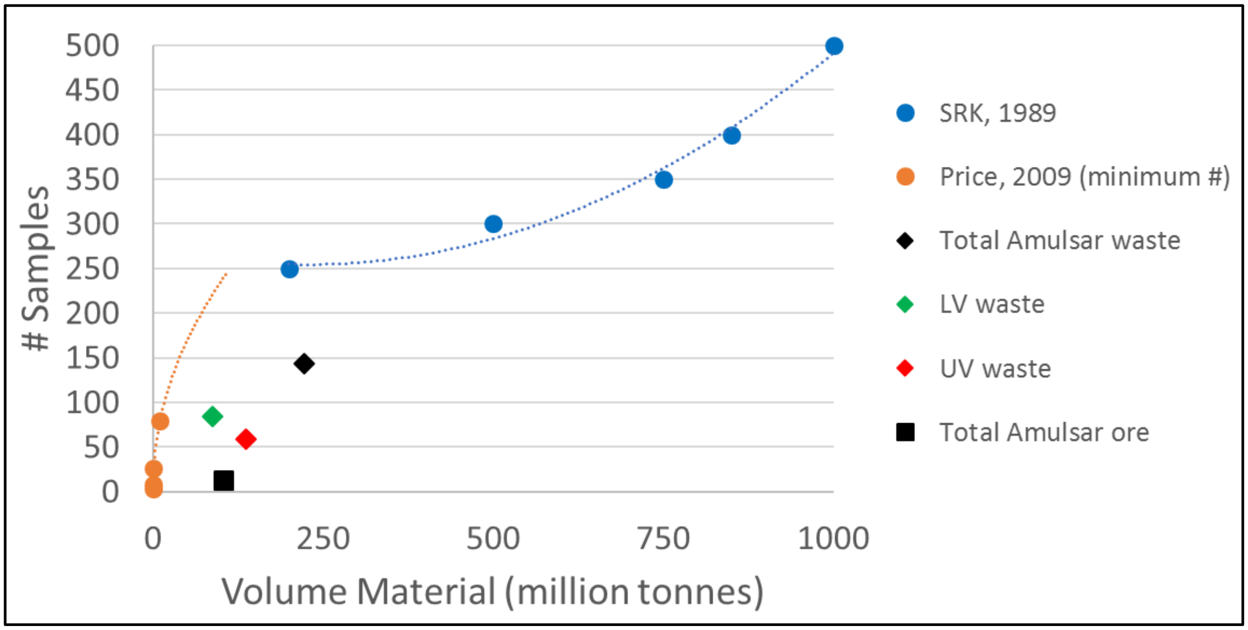
The projected costs for these three studies is $140,000, including laboratory costs. None of these studies address the shortcomings in the geochemical characterization program that are identified and discussed in this memorandum. As noted in the Bronozian consultants' reports (Blue Minerals Consultancy et al., 2017), we refute the claim that Amulsar waste is "naturally resistant to ferric iron oxidation ARD reactions." The geochemical characterization studies needed will undoubtedly increase the costs of the Amulsar Project and the measures needed for mine waste and acid rock drainage management.

3. Unresolved issues related to acid drainage and mine material characterization, and recommendations

Issue 1: Geochemical test units were not identified for Amulsar wastes

Sections 7.0 and 8.0 of the Lydian (2017) report discuss the geologic setting, mineralization, alteration, and deposit types of the Amulsar Project. A more regional picture of the geology is presented in Appendix 4.6.2 of the 2015 ESIA, which was not included in the 2016 ESIA. The

Figure 2: Comparison of recommended number of geochemical test samples (SRK, 1989 and Price, 2009 minimum number) and number of samples collected for Amulsar waste and ore.



Sources: Parbhakar-Fox and Dominy (2017); ESIA (2015) Appendix 4.6.2, Appendix Tables. SRK (1989) points are fitted with a 2nd-order polynomial curve, and Price (2009) points are fitted with a power function and forecasted forward for 100 periods using Excel.

information presented about the deposit demonstrates that the Amulsar site geology, mineralogy, and alteration are variable and complex. This is true for the UV and the LV rocks. For example, the degree of alteration in the UV and LV rocks significantly affects rock quality (Lydian, 2017, p. 139-140) and can also affect the ability to produce acid and leach metals and other mine-related contaminants. Despite this complexity, the *wastes* were not subdivided into geochemical test units – they were simply grouped into UV and LV materials for testing.

The spent *ore* was subdivided into four categories, based on similar mineralogy and alteration types, for metallurgical testing: pervasive iron oxide (MPF), gossan, fault gouge, and siliceous breccia (Lydian, 2017, Section 13.5), but very few geochemical tests were conducted on the ore. Acid-base accounting testing was conducted on spent ore using these same four categories (ESIA, 2015, Appendix 4.6.2, Section 5.4). These different ore units have quite different cyanide consumption rates (varying from 0.4 to 2.0 kg/t) and generate different amount of leachable metals, with Gossan generally having the highest concentrations (Lydian, 2017, p. 119 and Table 13.44, p. 153). These results suggest that establishing different geochemical test units for the ore is warranted.

Both waste and spent ore require geochemical/geoenvironmental characterization (Parbhakar-Fox and Lottermoser, 2015). Amulsar ore is proposed to be left on the landscape forever. Changes will occur to the material in the heap over time from oxidation and other reactions. The residual lime will deplete over time, and the planned rinsing with hydrogen peroxide during closure (ESIA, 2016, Appendix 6.9.4) will further promote the formation of acidic drainage. These changes require that samples of ore and spent and rinsed heap leachate should be collected and analyzed before mining begins, as the heap develops over time, and during closure/post-closure (Prabhakar-Fox and Lottermoser, 2016).

Recommendation: Examine mineralogy, including secondary mineralogy, and alteration to identify geochemical test units in UV and LV rock. Identify an appropriate number of representative samples and conduct additional ABA, whole rock, short-term leach tests, and kinetic tests on samples from each unit. This best practice approach will allow better separation and placement of potentially acid generating (PAG) and non-acid-generating rocks in the field and improved design of waste and ore management options.

Issue 2: UV waste and ore appear to have either uncertain ability to generate acid or are PAG, yet no additional testing is proposed

Using the acid-base accounting results, the UV samples either have an uncertain ability to produce acid drainage or are PAG. Using the net neutralizing potential (NNP = neutralizing potential (NP) – acid production potential (AP)) approach, most UV samples have uncertain acid-generation potential; using the neutralization potential ratio (NPR, or NP/AP) approach, most UV samples are PAG. The NP/AP ratio is preferred because it allows comparison of acid generation and neutralization potentials over a wide range of results (Tremblay and Hogan, 2000).

Even though the results show that the UV samples are PAG or uncertain, they are described as having "no" acid generating and metal leaching potential in various Lydian documents. Moreover, the ABA results for spent ore, which will be predominantly UV rock, show that the sulfide sulfur content is >0.3 wt. % in all but one sample and the NP:AP ratios are all below 1, which indicates PAG conditions (Lydian, 2017, Table 24.5). In addition, no additional testing of the acid generation potential of the UV material is proposed. Their conclusion that UV waste rock and spent ore are not acid generating contradicts the test results. And, as noted in Appendix 4.6.2 of the 2015 Amulsar ESIA, little to no neutralizing material is available in the Amulsar deposit.

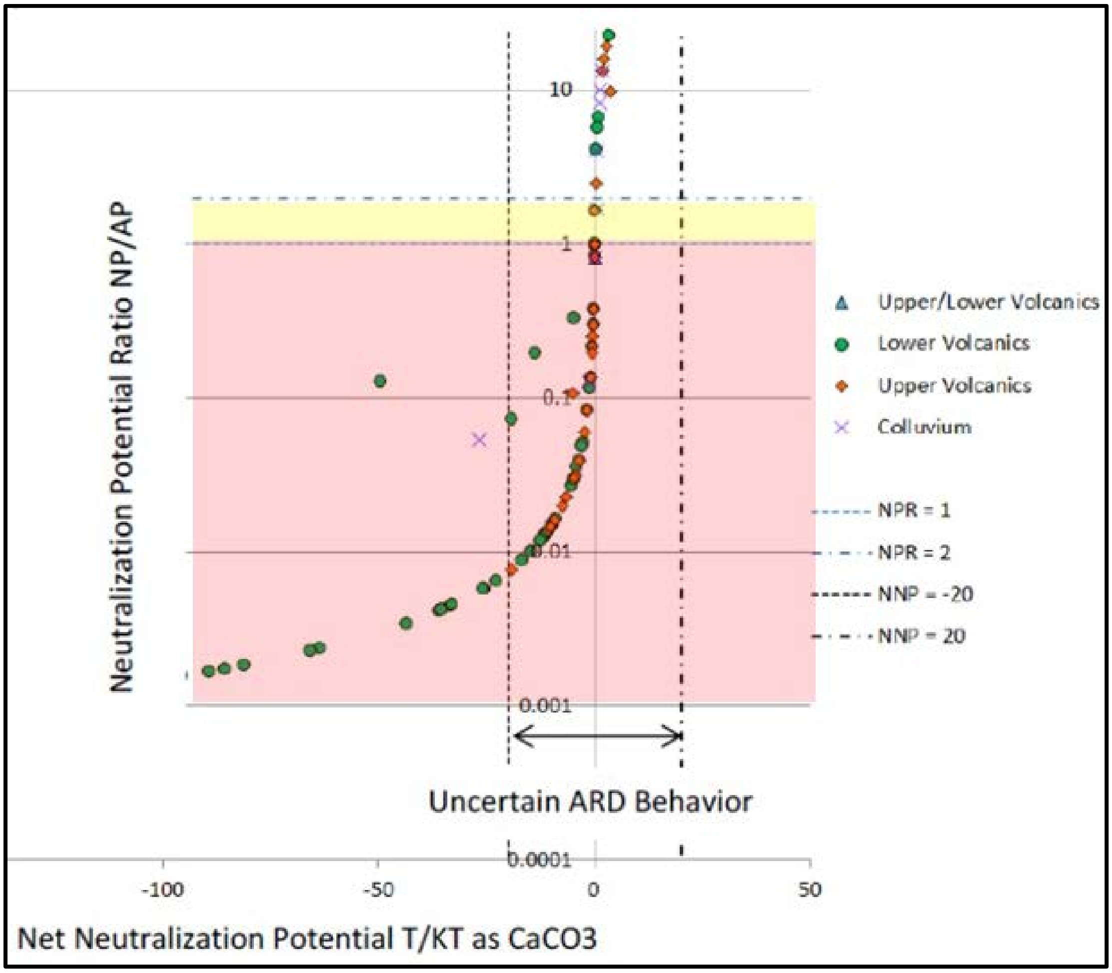
Figure 3 shows the samples that fall into the uncertain and PAG areas using the current NNP and NPR approaches. The yellow area contains the samples with uncertain ability to produce acid using the NPR, and the pink area contains samples designated as PAG using NPR and the criteria in Lydian, 2017, Table 24.4. Using the NPR approach, most samples are designated as PAG. However, Lydian (2017, p. 354) states "As demonstrated in Figure 24.1 all of the Upper Volcanics samples fall within the "uncertain" range. This signifies that kinetic testing is required to determine if these samples have ARD generation potential." Lydian is not following its own recommendation to conduct kinetic testing on the UV samples. To date, only three UV samples were subjected to kinetic testing, and no plans exist for additional long-term kinetic testing of UV materials. Testing related to "ferric iron resistance" using buckets and water quality test kits (Lydian, 2017, p. 397) does not qualify as long-term kinetic testing.

Recommendation: Conduct long-term (for at least one year) kinetic testing on spent ore and additional UV samples believed to be of uncertain acid-generating characteristics using the NNP approach. Re-evaluate the number of PAG samples using the NPR approach and the new kinetic testing results and incorporate the findings into planning for the management of PAG wastes.

Issue 3: Humidity cell tests were not conducted for long enough, too few samples were used, and the samples were not representative.

Only eight humidity cell tests (HCTs) were conducted: five from LV rock and three from UV waste rock samples. No ore samples were subjected to kinetic testing. The HCTs were conducted on samples with smaller mean and upper concentration ranges of mercury, antimony, arsenic, and

Figure 3. Acid-base accounting results of the Upper and Lower Volcanics waste samples showing ranges of uncertain and potentially acid-generating designations using two approaches. The yellow and red shaded areas were added to indicate samples in the uncertain and potentially acid-generating range, respectively, using the NP/AP ratio (NPR) approach.



Source: Modified from Lydian, 2017, Figure 24.1.

copper than those in LV or UV rocks as a whole (Buka Environmental, 2017). For example, mean whole rock concentrations for HCT samples were lower for all four elements, except for arsenic in UV rocks, and maximum values were 2 to 367 times lower in HCT samples, depending on the element. In addition, sulfide concentrations in the HCTs were not representative. Results from the HCTs, which are used to predict contaminant concentrations during and after operations, will therefore underestimate the leaching potential of mine wastes.

Of the three UV HCT samples, two were stopped at 20 weeks, which is much shorter than the year or longer recommended by Price (2009) and others or even Lydian itself for proving “beyond reasonable doubt that a rock sample will or will not generate acid” (Lydian, 2017, p. 357). Lydian’s independent review by Knight Piésold (2016) states that kinetic testing lasted for “a maximum of 55 weeks” but fails to mention that four of the eight tests were stopped at 20 weeks. This is especially important because all HCTs that had neutral pH leachate initially went on to produce acidic water if they were run for over 20 weeks (ESIA, 2015, Appendix 4.6.2, Figure 8-1). The acid-generating and metal leaching potential of Amulsar wastes and spent ore cannot be adequately determined without more kinetic testing using more representative samples and longer test lengths.

Two LV samples (75C and 77C) contained high proportions of alunite[2] - 53% and 21%, respectively – and no pyrite, yet both samples produced acidic drainage with pH values below 5; a UV sample with 70% alunite and no pyrite also produced acidic drainage with a pH below 6 (ESIA, 2015, Appendix 4.6.2, Appendix C-1 and Figure 8-1). These results demonstrate that pyrite is not the only source of acid drainage at Amulsar and more mineralogic analysis is needed.

Recommendation: Conduct HCTs for longer than one year on waste and ore samples using identified geochemical test units. Ensure that mineralogy and alteration are carefully identified and selected samples are representative of the range of total metal concentrations rather than focusing on samples with lower metal concentrations. After these tests are re-run and defensible data on water pH and metal leaching are obtained, predictions of operational water chemistry should be revised to account for these results.

Issue 4: Short-term leach tests used to characterize contaminant/metal leaching potential produced dilute leachate from non-representative rocks

The synthetic precipitation leach procedure (SPLP) and the net acid generating (NAG) effluent test were used to estimate the short-term leaching behavior of 16 (for SPLP) or 18 (for NAG) waste rock samples (Tig/Art + Erato); a total of 13 spent ore samples were subjected to SPLP, Toxicity Characteristic Leaching Procedure (TCLP), and NAG testing (ESIA, 2015, Appendix 4.6.2, Appendix D). The short-term leach tests used a high solution:solid ratio, which will dilute final effluent concentrations. The SPLP and TCLP tests used a 20:1 ratio, and the NAG method used a 100:1 solution:solid ratio. Based on these results, cadmium and chromium were eliminated as contaminants of potential concern, whereas another procedure might have ruled them to be of concern. Contaminants of potential concern should not be eliminated using these short-term test results because of the high dilutions.

Recommendation: Conduct short-term leach tests on material from the geochemical test units using commonly-used tests with lower or variable solution:solid ratios, such as the Meteoric Water Mobility Procedure or variable solution:solid ratios. Re-examine the contaminants of potential concern for short-term leaching using the new results.

Issue 5: Encapsulation of PAG LV rocks was not tested for effectiveness

One of the primary mitigation measures used to prevent or minimize the formation of acid drainage is encapsulation of PAG LV rocks in the barren rock storage facility (BRSF). The identified PAG LV waste rock is proposed to be wrapped in "non-acid-generating" UV waste rock (ESIA, 2016, Appendix 8.1.9). Neither the LV nor the UV waste rock has any notable acid-neutralizing capacity, but the encapsulation with UV rock is predicted to minimize contact of the PAG rock with infiltration, seepage, and oxygen. The Lydian (2017, p. 271) report states: "…it (is) anticipated that the argillic clay minerals will facilitate compaction and a reduction in hydraulic conductivity with the PAG cells." Lydian's response to the Bronozian reports (Wardell-Armstrong, 2017) states that encapsulation testing for the BRSF will be conducted over the next year (with no details provided), and that encapsulation is an industry-standard ARD management approach, citing the GARD Guide (2017). However, the GARD Guide discusses the use of acid-consuming materials in encapsulation rather than clay minerals. As noted above, no acid-consuming materials are present at the Amulsar site Knight Piésold (2016) declared the encapsulation approach "appropriate" with no citations or

[2] A hydrated aluminum sulfate mineral known to produce acid (Dold, 2017).

additional investigation. Without supportive evidence, one must take on faith that this mitigative measure will effectively prevent acid generation.

Recommendation: Test encapsulation assumptions and consider adding neutralization material to PAG materials before encapsulating or backfilling.

4. Summary

Additional geochemical characterization testing is needed on Amulsar ore and wastes to determine the short- and longer term environmental behavior of mined materials that will be left on the land surface or in backfilled mine pits forever. The results to date have been interpreted optimistically, and the full potential for acid generation and metal leaching has not been acknowledged in the Lydian reports or the report of their independent evaluator. Given that wastes generated by past mining activity have generated acidic drainage, a more conservative interpretation is warranted. Much more work is needed especially on the spent ore and the UV rocks, which have been prematurely declared to be non-acid-generating. Mined material characterization is crucial for more defensible prediction of operational and closure/post-closure water quality, and for effective mitigation measures that rely on the results of these tests.

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