BUKA ENVIRONMENTAL
Boulder, CO 80302 USA
303.324.6948/aamaest@gmail.com

RESPONSE TO STATEMENTS BY LARRY BRECKENRIDGE OF GRE REGARDING AMULSAR GEOCHEMICAL CHARACTERISTICS

Summary

- This memorandum responds to statements made by Larry Breckenridge, an engineer with GRE, regarding the pollution generating characteristics of the Amulsar Gold Project in Armenia.
- Larry Breckenridge claims that none of the Amulsar ore and only a portion of the barren (waste) rock will generate acid. These statements are not supported by Lydian's own results and ignore the fact that, because of geologic complexities at the site, waste will be difficult to successfully separate from ore.
- Lydian states that Mr. Breckenridge is an independent expert, but his company, GRE, has conducted numerous technical studies and reports for Lydian and the Amulsar Project.
- Lydian has underestimated the acid-generation potential of Amulsar's ore and waste because it is using an outdated interpretation approach that is not recommended by the GARD Guide, which Lydian documents continually cite and say they are following. Using the approach recommended by the GARD Guide, nearly all the ore and waste samples analyzed are potentially acid-generating.
- Lydian's mitigation measures for preventing or minimizing the release of acid are based on incorrect assumptions about the acid-generating and contaminant leaching potential of their ore and wastes.
- Mr. Breckenridge's statements about the lack of acid-generation potential ignore or do not mention the potential for the mine to leach other contaminants to nearby streams and groundwater. The results show that leachate from the waste rock and the spent ore facilities at Amulsar will contain concentrations of metals, sulfate, and nitrate well above Armenian water quality criteria during and for many years after mining ceases. The close proximity to streams and the abundant faults suggest that contaminants will quickly reach surface water and springs with little attenuation.
- Given the high potential of Amulsar waste and ore to leach contaminants and the lack of consideration of this fact in the design of the mine facilities, the waste rock storage and heap leach facility should be completely redesigned using best practices. In addition, placement of the facilities farther away from streams and closer to the pit should be seriously considered.

Introduction

This memorandum is written in response to statements made by Larry Breckenridge, of Global Resource Engineering Ltd. (GRE), in an Armenian press article (ARMENPRESS, 2018) and in an article on the Lydian Armenia website (Lydian Armenia, 2018). Mr. Breckenridge is described as an "independent expert" (Lydian Armenia, 2018), yet GRE has prepared many documents for the Amulsar Project, including, at a minimum: the Acid Rock Drainage Management Plan (2016), the Site Wide Water Balance (2014), the Summary Geochemical Characterization and Water Quality Prediction: Update (2014), the Summary of Geochemical Characterization and Water Quality Prediction – Revised: Amulsar Gold Project (2014), Amulsar Pit Dewatering Model (2014), and the Amulsar Barren Rock Storage Facility Design Report (2015).[1] Considering his position with GRE as Principal Environmental Engineer[2] and GRE's extensive previous contracting with Lydian, Mr. Breckenridge cannot reasonably be considered an independent expert.

Mr. Breckenridge states that the Amulsar ore is fully oxidized and has no acid generation potential, and that only a portion of the barren rock has the potential to form acid drainage (ARMENPRESS, 2018). The ore is largely confined to the Upper Volcanic material.

> "One important clarification is that Amulsar ore is indeed fully oxidized and the acid generation potential is not with the ore itself, but with the barren rock. Barren rock is rock that must be removed from the pit to gain access to the ore. Some of the barren rock has the potential to generate acid and Lydian has disclosed this fact in all its relevant documents. Lydian has also maintained that the acid rock drainage conditions are manageable and controllable. One of the reasons for this is because the ore is not an acid rock drainage risk, but instead, only a portion of the barren rock."

He further states that discharge of any mine-influenced water will not occur because it will be fully used in the mining process, except during closure, when a passive treatment system will be installed (ARMENPRESS, 2018):

> "All contact water will be collected and used in the mining process. Consuming all potentially-impacted water prevents discharge to the environment, and therefore, the impact on the quality of nearby streams and lakes. And finally, as an additional measure, upon closure, the project will install a modern passive treatment system that will treat any water that flows into the environment after the mine is completed."

The available data and information in Lydian's reports refute these claims.

---

[1] As noted in the References sections of Samuel Engineering, 2017 and Geoteam, 2016.

[2] See: http://www.global-resource-eng.com/team/

Likelihood that Amulsar Ore and Waste Will Generate Acid

General Considerations

Lydian claims they are using the Global Acid Rock Drainage (GARD) Guide (INAP, 2009) approach for identifying samples as potentially acid generating (PAG), as shown in Table 1 (Samuel Engineering, 2017). Net neutralization potential (NNP) is defined in the current version of the GARD Guide, but no screening criteria are defined.[3] However, net neutralizing potential (NPR) is defined and used exclusively in Chapter 5 of the GARD Guide. Lydian has chosen to rely on the outdated NNP criterion to define whether samples are PAG. Using the NPR approach, and assuming no errors in the estimation of "true" or effective NP and AP, samples with NP<AP are considered PAG.

Table 1. Lydian's screening guide for determining whether samples are potentially acid generating (PAG)

Material Designation	Comparative Criteria	
	NNP ($TCaCO_3$/kT)	NPR
Potentially Acid-Generating (PAG)	< -20	< 1
Uncertain	-20 < NNP < 20	1 < NPR < 2
Non Potentially Acid Generating (NAG)	> 20	> 2

Source: Samuel Engineering, 2017, Table 24.4. NNP = net neutralizing potential, NP-AP; NPR = neutralizing potential ratio, NP/AP. AP = acid production potential; NP = neutralization potential.

The NNP approach favored by Lydian underestimates the number of Amulsar samples that are PAG. As shown in Figure 1a, using the NNP approach, only some of the LV samples (green circles) are PAG (pink area), and all the UV samples (red diamonds) have an uncertain ability to generate acid (yellow area). The results using this approach match the statement by Mr. Breckenridge that "Some of the barren rock has the potential to generate acid…" Figure 1b depicts the results using the NPR approach recommended by the GARD Guide. These results contradict Mr. Breckenridge's statement and show that nearly all the LV and UV samples are PAG.

The GARD Guide also recommends directly adding in the sulfur from acid-producing sulfate minerals to calculate acid production potential (AP):

AP = 31.25 (% sulphide-S + % acid sulphate-S)[4]

As noted in several of our previous reports, jarosite and alunite are abundant in Amulsar rocks, and the HCT results demonstrate that these hydrated sulfate minerals produce acid when weathered under oxidizing conditions. The percent sulfate-S is available, but Lydian also chose not to use the GARD Guide recommendation in this instance. If the percent acid sulfate-S was added in to calculate AP, even more samples would be considered PAG.

---

[3] *GARD Guide source:* http://www.gardguide.com/index.php?title=Chapter_5b#top

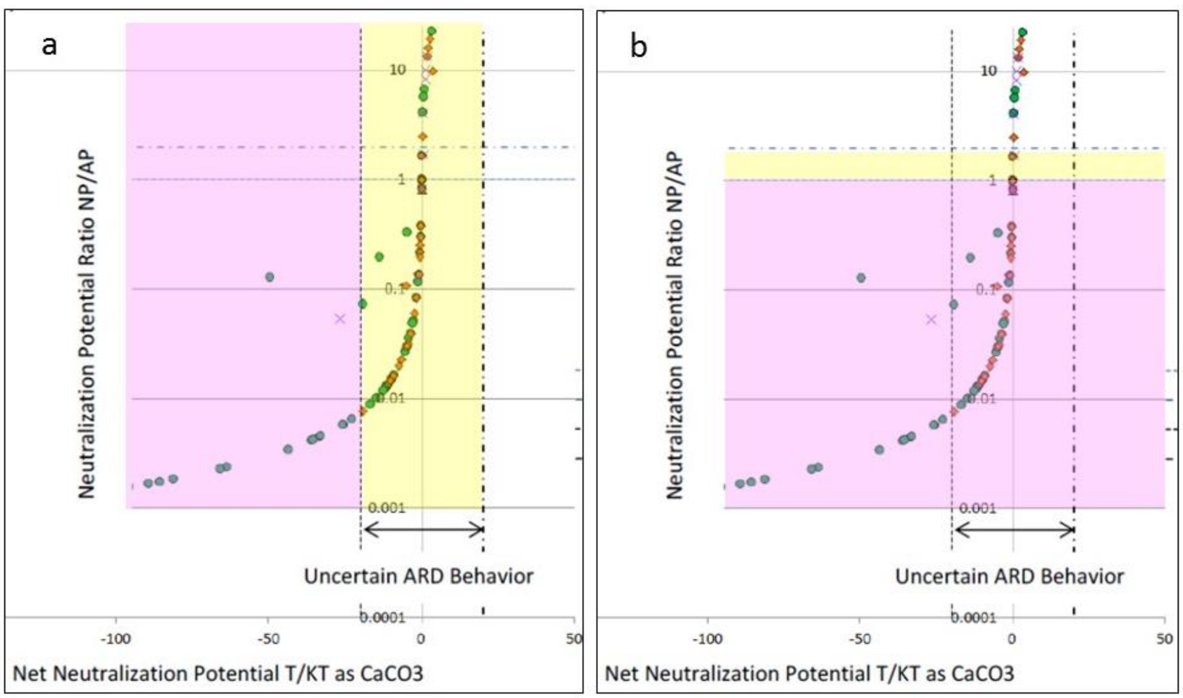
[4] http://www.gardguide.com/index.php?title=Chapter_5b#5.4.10_Net_Acid_or_ARD_Potential

In addition to errors in interpreting the ABA results of Amulsar ore and waste, Lydian has underestimated the difficulties involved in separating Upper and Lower Volcanic material at the site. As shown in Figure 2, the geology is complicated by faults and folds, and Lower Volcanic waste material is mixed throughout the deposit rather than simply being stratigraphically below the Upper Volcanic ore material.

Amulsar Ore

The acid generation potential of spent ore is important to examine because the heap leach facility (HLF) will contain spent ore that will sit on the earth's surface in perpetuity. According to Lydian documents, the ore is contained largely in the Upper Volcanic material. Using NPR as the approach to determine if a sample is PAG, all samples of Amulsar spent ore shown in Table 2 except MPF are PAG. The one Erato sample, MC068, is also PAG. Lydian proposes to add lime to the ore in the HLF (Geoteam, 2016; lime is needed to raise the pH for gold-cyanide complexing). This increased neutralizing ability is taken into account in the spent ore samples, which contain lime and are representative of the material that would be in the heap after cyanide extraction during operation and closure.

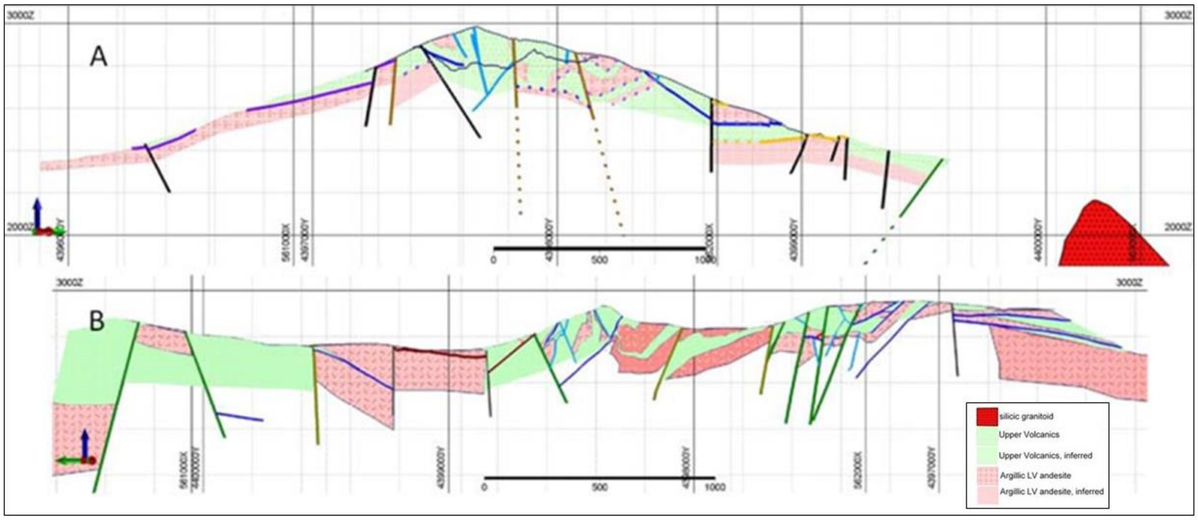
Figure 1. Comparison of two approaches for determining PAG samples from ABA results. a. results using the NNP approach; b. results using the NPR approach. Green circles are Lower Volcanic samples, and red diamonds are Upper Volcanic samples; the blue Xs are colluvium samples. The pink shading indicates the area in which sample results are considered to be PAG, and the yellow shading indicates the area in which sample results indicate an uncertain ability to generate acid.



Source: Modified from Samuel Engineering, 2017, Figure 24.1.

As noted in my previous memo (Buka Environmental, 2017), very few samples of spent ore have been collected and analyzed for their potential to generate acid. Many more samples are needed to estimate the potential of different parts of the pits and the spent ore heap leach facility to generate acid. However, when nearly all spent ore samples to date are PAG, one must assume that the walls of the pits and the heap leach facility (HLF), which will remain on the surface forever, will generate acid for a very long time.

Figure 2. Two geological and structural cross-sections through the proposed Amulsar Tigranes-Artavasdes open pits. Upper Volcanic material is shown in green, while Lower Volcanic material is shown in pink.



Source: Samuel Engineering, 2017, Figure 7.3.

Table 2. Acid-base accounting results for Tigranes/Artavasdes spent ore.

Sample	Total Sulfur	Acid Soluble Sulfate	Sulfide Sulfur	AP	NP
	%	%S	%	T CaCO3/kT	T CaCO3/kT
MPF	0.04	0.02	0.02	0.63	3.06
GSN	0.58	0.05	0.53	16.50	4.31
FG	0.37	0.06	0.31	9.59	2.69
SB	0.38	0.04	0.34	10.66	2.31
MC0681,2	1.15	0.03	1.13	35.16	1.37
MC0701	0.70	0.05	0.65	20.22	2.50
MC0711	0.38	0.01	0.37	11.63	0.69
Notes: 1. Composite sample 2. Erato sample					

Source: Samuel Engineering, 2017, Table 24.5.

The Erato samples in Table 3 generally have more sulfate sulfur than sulfide sulfur, and these samples may not be PAG unless the sulfate minerals are acid producing. However, samples DDA-278 and DDA-276 are PAG, and the Erato sample in Table 3 is PAG. Importantly, neither sample set is large enough to be representative of the range of acid-generation potential in either pit.

Table 3. Acid-base accounting results for Erato spent ore

Sample	Total Sulfur	Acid Soluble Sulfate	Sulfide Sulfur	AP	NP
	%	%S	%	T CaCO3/kT	T CaCO3/kT
DDA-030	0.95	0.24	<0.01	0.31	0.30
DDA-030	0.14	0.11	<0.01	0.31	0.30
DDA-278	0.74	0.20	0.10	3.13	0.30
DDA-276	1.75	0.32	0.09	2.81	0.30
DDA-290	0.00	0.02	<0.01	0.31	0.30
DDA-340	0.53	0.24	<0.01	0.31	0.30

Source: Samuel Engineering, 2017, Table 24.6.

Amulsar Waste

Barren rock, or waste rock, will be produced from mining at Amulsar. These wastes will be placed in the Barren Rock Storage Facility (BRSF) or used as a partial backfill for the Tigranes/Artavasdes (Tig/Art) pit and sit on the earth's surface forever. In addition, the walls of the open pits will contain waste material that will have the potential to generate acid before the Tig/Art pit is backfilled or in perpetuity, for the portions that will be permanently above the backfill or in the Erato pit, which will not be backfilled.

The ABA results for the Upper and Lower Volcanic samples are shown in Figure 1 for individual samples and Table 4 for mean values. As noted in the Introduction, using the GARD Guide recommendation for interpretation of ABA results (NPR approach), nearly all the Upper and Lower Volcanic samples are PAG (see Figure 1 and associated text). In general, Lydian has states that the waste rock will be Lower Volcanic material. The mean results for barren rock (results shown for Lower and Upper Volcanic waste), also demonstrate that Amulsar waste is PAG. The results in Table 4 also show that the waste has almost no neutralizing potential (NP); therefore, if acid does form, and it is highly likely that it will, the material in the BRSF or the pits will have almost no ability to neutralize the acid. The acid rock drainage management plan (Geoteam, 2016) does not propose to add any neutralizing amendments to the waste in either the BRSF or the backfill. While encapsulation of material in the BRSF is proposed, the encapsulating material will not contain lime or other neutralizing amendment, so acid produced in the facility will not be neutralized. Lydian is proposing to encapsulate the assumed limited amount of PAG material in the BRSF, but the ABA results show that the entire facility will be acid-generating.

Likelihood that Amulsar Ore and Waste Will Leach Contaminants

Mr. Breckenridge's statements about the lack of acid-generation potential ignore or do not mention the potential for the mine to leach other contaminants that can reach nearby streams and groundwater.

Table 4. ABA results for Tigranes/Artavasdes barren rock (first table) and Erato barren rock (second table). Average (mean) values for Lower and Upper Volcanic samples are highlighted in yellow.

Barren Rock	Statistics	Paste pH	AP $TCaCO_3/kT$	NP $TCaCO_3/kT$	Total S %	Sulfide S %	Sulfate S %
Lower Volcanics	Mean	4.86	40.94	0.26	2.51	1.31	0.36
	Std. Dev.	1.07	60.00	1.67	2.57	1.92	0.55
Upper Volcanics	Mean	5.54	4.30	0.14	0.76	0.14	0.11
	Std. Dev.	0.70	21.39	0.85	1.40	0.68	0.20
Colluvium	Mean	5.79	0.87	0.20	1.07	0.03	0.13
	Std. Dev.	0.84	1.02	0.41	1.27	0.03	0.11

Barren Rock	Statistics	Paste pH	AP $TCaCO_3/kT$	NP $TCaCO_3/kT$	NAG pH	Total S %	Sulfide S %	Sulfate S %
Lower Volcanics	Mean	5.00	27.44	0.38	4.28	2.16	0.88	0.38
	Std. Dev.	1.04	49.26	0.96	1.12	2.23	1.58	0.60
Upper Volcanics	Mean	5.30	5.48	0.27	4.72	0.83	0.18	0.11
	Std. Dev.	0.60	24.62	0.85	0.50	1.43	0.79	0.15
Colluvium	Mean	5.75	5.33	1.08	4.92	1.69	0.17	0.20
	Std. Dev.	0.19	11.19	0.86	0.15	2.42	0.36	0.28

Source: Samuel Engineering, 2017, Tables 24.2 and 24.3.

Predicted Barren Ore Leachate Quality Years after Closure

Table 5 shows the predicted concentrations in HLF barren and detoxified solutions during and after closure. Based on the HLF risk assessment conducted by Golder Associates (2014a) and the results in Table 5, the constituents of potential concern for discharge to surface water include: aluminum, ammonia, antimony, arsenic, beryllium, chloride, chromium, cobalt, copper, cyanide, iron, nitrate, selenium, sodium, sulfate, and zinc (Golder Associates, 2014a, p. 11; Golder identified several more). Armenia does not have groundwater quality standards, but antimony, arsenic, copper, (barren solution), cyanide, nitrogen (if present as nitrate), and sulfate concentrations in Table 5 exceed U.S. drinking water standards. Table 6 shows the HLF barren leach solution concentrations during operations, based on testwork conducted by Wardell Armstrong on Amulsar ore. Antimony, arsenic, copper, and zinc are potential contaminants of concern for HLF leachate during operations.

Predicted Waste Leachate Quality Years after Closure

The predicted waste rock leachate concentrations after closure are shown in Table 7. The highlighted values exceed project surface water quality standards and are potential contaminants of concern for the barren rock.

The results show that leachate from the waste rock and the spent ore facilities at Amulsar will contain concentrations of metals, sulfate, nitrate, and cyanide well above Armenian surface water quality standards. Despite the predictions by Golder Associates showing that little to no impact will occur to groundwater or surface water, the close proximity to streams and groundwater and the abundant faults suggest that contaminants will quickly reach surface water, shallow groundwater, and springs with little attenuation.

Table 5. Barren solution and detoxified solution analysis during and after closure (mg/L). Values in shaded cells exceed applicable surface water standards for the Amulsar Gold Project.

Parameter	Arpa MAC II Standards	Final Barren Solution		Final Detoxified Solution	
		Test 61781	Test 61790	Test 61781	Test 61790
Aluminum	0.144	1.1	6.6	0.38	2.4
Antimony	0.00028	0.12	0.04	0.19	0.061
Arsenic	0.02	0.63	0.15	0.7	0.18
Copper	0.021	1.4	1.5	0.58	0.5
Cyanide (WAD)	0.5	34	66	0.44	0.036
Total Nitrogen (as N, calculated)	--*	78	81	23	31
Selenium	0.02	0.0056	0.049	0.0071	0.047
Sodium	10	310	400	26	340
Sulfate	16.04	45	390	140	590
Zinc	0.1	0.24	0.36	<0.010	0.028

*Source: Golder Associates, 2014a, Table 2. * Values are the calculated sum of nitrate+nitrite and total Kjeldahl nitrogen; Armenia has no surface water standard for total nitrogen.*

Table 6. Barren leach solution concentrations during operations, multi-element assay results. Results in red exceed the Arpa MAC standard.

Analyte	Units	Arpa MAC Standards	MPF	FG	SB	GSN	MC 068	MC 070	MC 071
Antimony	mg/L	0.00028	0.053	0.03	0.202	0.088	0.022	0.024	0.017
Arsenic	mg/L	0.02	1.06	0.658	0.529	4.19	0.194	0.326	0.103
Copper	mg/L	0.021	0.667	0.901	0.765	1.52	0.551	0.507	0.384
Mercury*	µg/L	--	0.038	0.189	<0.010	0.93	0.017	0.042	0.044
Zinc	mg/L	0.1	0.969	1.34	0.815	2.17	0.713	0.854	0.538

Source: Samuel Engineering, 2017, Table 13.44.
World Bank/IFC EHS Effluent Standard and the US Safe Drinking Water Act standard for mercury are 2 µg/L.
Abbreviations: MPF=medium pervasive iron oxide; FG=fault gouge; SB=siliceous breccia; GSN=gossan; MC 068, MC070, and MC071 are composite samples from the Erato, Artavazdes, and Tigranes pits, respectively.

Table 7. Predicted Leachate Quality from Barren Rock Storage Facility during Post-Closure. Red sharing added to show predicted concentrations of contaminants of potential concern for aquatic life or human health that exceed applicable water quality standards.

Constituent	Units	Arpa MAC (Category II)	Estimated Post Closure Concentration
Al	µg/l	144	164,399
As	µg/l	20	104.9
Ba	µg/l	28	9.2
Be	µg/l	0.038	12.2
B	µg/l	450	55.5
Cd	µg/l	1.014	2.2
Ca	mg/l	100	42.7
Cl-	mg/l	6.88	1.3
Cr+3	µg/l	11	0.1
Co	µg/l	0.36	622.9
Fe(3)	mg/l	0.072	0.5
Pb	µg/l	10.14	244.3
Li	µg/l	3	53.2
Mg	mg/l	50	20.3
Mn	µg/l	12	281.2
Ni	µg/l	10.34	373.8
Nitrate	mg N/l	2.5	365*
K	mg/l	3.12	35.0
Se	µg/l	20	52.8
Sulphate	mg/l	16.04	412.3
P	mg/l	0.2	5.2
V	µg/l	10	14.3
Zn	µg/l	100	2264.1

**Based on the average total nitrogen loading reported in Golder, 2014e*

Source: Golder Associates, 2014. Table 1.

References Cited

ARMENPRESS, 2018. Acid rock drainage at Amulsar will be controlled and will not negatively impact water quality – international expert. January 22. Available: https://armenpress.am/eng/news/919737/amulsarum-ttvayin-aparneri-drenazhic-shrjaka-jrayin-hamakargeri.html Also linked to from Lydian Armenia website: https://www.lydianarmenia.am/en/news/view/larry-breckenridge-on-ard.html

Buka Environmental, 2017. Evaluation of Geochemical Characterization Results and Proposed Additional Studies for the Amulsar Project, Armenia. 30 October 2017. 9 pages. Available: https://goo.gl/9zGbq8

Geoteam, 2016. Amulsar Gold Project. Acid Rock Drainage Management Plan Report. June. Included as Appendix 8.19 of the Amulsar ESIA. Available: https://www.lydianarmenia.am/resources/mainFiles/pdf/174d63294134a54bbed0bd71f3156d92.pdf

The International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide). Available: http://www.gardguide.com/ Accessed on 11 February 2018.

Lydian Armenia, 2018. International Expert Gave Comprehensive Clarifications to Questions of Public Concern on the Amulsar Project. Available: https://www.lydianarmenia.am/index.php?m=newsOne&nid=156

Samuel Engineering, 2017. NI 43-101 Technical Report. Amulsar Updated Resources and Reserves, Armenia. Prepared for: Lydian International, March. Available: http://www.lydianinternational.co.uk/images/TechnicalReports-pdfs/2017/Lydian_43-101_March_30,_2017.pdf

Golder Associates, 2014a. Technical Memorandum: Amulsar Gold Project – Hydrogeological Risk Assessment Proposed Heap Leach Facility. Prepared for: Lydian International. August. Included as Appendix 6.9.4 in the Amulsar ESIA. Available: https://www.lydianarmenia.am/resources/mainFiles/pdf/a8897a39ca323ab730b406e0fc115570.pdf

Golder Associates, 2014b. Technical Memorandum: Amulsar Project – BRSF Risk Assessment of Hydrologic Impacts. Prepared for: Lydian International. August 26. Included as Appendix 6.9.5 in the Amulsar ESIA. Available: https://www.lydianarmenia.am/resources/mainFiles/pdf/5859346e489c66adf65ea6c7dd4f4790.pdf