CLEAR COAST
CONSULTING, INC.

MEMORANDUM

Date: **June 13, 2017**

To: **Harry Bronozian**

From: **André Sobolewski, Clear Coast Consulting, Inc**

Subject: **Review of water treatment at the proposed Amulsar Gold project**

I have review several documents relating to the proposed Amulsar Gold project to evaluate water treatment solutions proposed to mitigate project impacts. These documents include:

- Amulsar Appendix 4.6.2 Geochemical Characterization and Prediction, Global Resource Engineering (GRE) Report, August 2014
- Amulsar Appendix 8.19 Acid Rock Drainage Management Plan (ARDMP), GRE Report, February 2015
- Amulsar Appendix 18 Environmental Design Criteria, Samuel Engineering Report, August 2015
- Amulsar Passive Treatment System Design Basis, Memo by Sovereign Consulting, December 2015
- Acid Rock Drainage Management Plan, Geoteam Report, June 2016
- Environmental and Social Impact Assessment, Chapter 8, Wardell Armstrong, June 2016
- Amulsar Updated Resources and Reserves, NI 43-101 Technical Report, Samuel Engineering, March 2017

I also reviewed the assessment of acid rock drainage (ARD) development by Blue Minerals Consultancy and by Ann Maest on your behalf.

These documents were reviewed to determine the adequacy of water management measures and treatment systems proposed to prevent environmental impacts by the proposed project.

This project has attracted attention and various organizations have stated positions both in favour and against it. My mandate is to review impartially the proposed project and to draw on my knowledge, professional judgement and experience to identify potential flaws and deficiencies. My professional qualifications for conducting this review are appended in a separate document.

1 Objectives and Approach of this Review

The overall objective of this review is to evaluate the viability of water treatment options at the Amulsar Gold project during operation and post-closure. During operations, the mine is proposed to be a zero-discharge facility. At closure, the proposed passive treatment systems for the closed Heap Leach Facility (HLF) and Barren Rock Storage Facility (BRSF) are two elements of an overall mine closure strategy. Other elements include the development of covers, HLF rinsing followed by release of drain down water, encapsulation of reactive waste rock, development of collection ponds, etc. The likely effectiveness of proposed measures has been assessed, though they are only discussed at the conceptual level in the above documents.

Two central aspects of water treatment system design were considered in my evaluation:

1. Were there accurate predictions of average and maximum water flows and chemistry that can support an effective treatment system design?
2. Were appropriate technology(ies) selected that will produce acceptable discharges for all contaminated waters produced at this site?

The detailed analysis of predicted water chemistry after mine closure has been conducted by other members of the review team. Drawing on my professional experience and judgement[1], I also evaluated the predicted post-closure water chemistry, with the specific objective of determining the suitability of proposed passive water treatment schemes.

2 Mine Development

Three aspects of mine development will be problematic in relation to the management and treatment of contaminated water:

1. Pit Dewatering
2. BRSF Development
3. Mine Expansion

The provisions for managing contaminated acidic mine water from each of these sources, as described in the ARD Management Plan, are poorly considered. In particular, it may be necessary to develop a lime treatment plant to control ARD during operations, especially if mine life is extended past the planned 10 years. This need for a lime-based treatment plan will have a

[1] For example, I draw on my experience with heap leach operations at Beal Mountain, Brewery Creek and Yanacocha, and on my experience at Nickel Plate Mine, to predict the formation of thiocyanate during the operation of the heap at Amulsar.

significant economic impact on the project and represents a risk that should be accounted for in the evaluation of the proposed mine plan.

2.1 Pit Dewatering

Pit dewatering is predicted to produce flows of 63-100 L/s. This water will comprise acidic groundwater that is intercepted by the developing pit and drain to the pit bottom. This drainage may contain aluminum and iron, and possibly other toxic metals. Additionally, alunite and jarosite on the wall face will be washed out by precipitation and report to the pit sump. They will also contribute aluminum and iron, and possibly other associated metals. This acidic water will be diverted to the BRSF contact-water pond, and thence to the HLF detention pond.

In some regards, this scenario is very reminiscent of the Golden Sunlight Mine, where both acidic groundwater and acid-generation oxidation products were drained from the wall face of the pit and reported to the bottom sump (Figure 1). While the specific composition of this drainage may be different, the similarity of their sources is striking.

Figure 1. Acid drainage collecting in the pit bottom sump at Golden Sunlight Mine. Note the orange colour of the water in the pit sump, indicative of the acid water draining into the pit.

The acidic water collecting in the bottom of the pit requires neutralization. Sending this water to Pond PD-7 and the HLF detention pond and adding lime to neutralize pH will cause metals to become insoluble, but the resulting precipitates will not settle easily[2]. As long as the volume of acidic water from pit dewatering is much smaller than that of the barren solution, this will remain a trivial problem. However, this problem may become too difficult to ignore throughout mine life, as the volume of acid water increases, lime consumption increases and the volume of sludge resulting from neutralization becomes significant.

[2] These solids will be predominantly hydrated aluminum sulfate hydroxides and iron hydroxides, which will form thin slurries in the detention ponds.

Proper solid settling will require addition of coagulants and settling in a clarifier or lamellar settling system, or use a Rotating Cylinder Treatment System (RCTS™) or similar. The alternative – applying this slurry on the heap – may be inadvisable because these precipitates will be filtered and potentially blind ore and reducing gold recovery, especially if pit water contains >20 mg/L aluminum and/or iron.

2.2 Development of the BRSF

The problem of managing acidic water from pit dewatering will be compounded by the generation of acidic drainage by the BRSF.

A significant portion of the waste rock placed in the Barren Rock Storage Facility (BRSF) will be reactive. The Humidity cell testwork shows that some of this waste rock (particularly from the Lower Volcanics) will react very rapidly (a few months), produce acid drainage and release aluminum, iron and sulfate. It is planned that this contact water will go to the Process Water Conditioning Plant (and to the HLF detention pond), together with acid drainage from pit dewatering, where it will be neutralized and the resulting metal precipitates are said to settle..

The combined flows from pit dewatering and BRSF leachate that report to Pond PD-7 may reach up to 150 L/s during wet years and contain 20-30 mg/L aluminum. Neutralizing this water will produce complex hydrated aluminum hydroxysulfates that do not settle easily. Additionally, any iron hydroxides formed during neutralization will also resist settling without coagulants and/or flocculants. There resulting solids may need more than >5 days retention time to settle properly.

This slurry may be applied to the heap, but continual addition and filtration of the solids may affect its performance and gold recovery. This will become increasingly problematic during mine life, as the combined flows from pit dewatering and BRSF drainage increase and metal loads increase. At that time, Lydian may consider establishing a separate lime treatment plant and solid settling system to treat this drainage.

Generally, it is not a good practice to place reactive rock in waste rock dumps, even if isolated with a soil cover, especially highly-reactive sulfides. The latter will generate hot spots that cause temperature gradients and internal thermal currents, which will stress the soil cover. Additionally, rapid weathering of highly-reactive rock may also decrease the structural integrity of the rock and result in uneven settling and subsidence of the pile, which may breach the integrity of the soil cover. A better alternative would be to segregate the sulfides from the rest of the waste rock and dispose of it separately, eventually backfilling it in a mined out pit. This approach was reviewed favourably in a recent MEND report[3] that presents the approach, reviews 12 case studies and summarizes lessons learned from applying this practice at mines around the world.

2.3 Expansion of Mine Life

The NI 43-101 report suggests that the 10 year life for the planned mine is a minimum:

> *The estimated mine life is a little under 10 years, however, the model contains a significant portion of inferred material, and drilling has identified additional mineralization below the pits that has not been quantified by detailed drilling.*

As mine life expands beyond the planned 10 years, more acidic water will drain from pits, more reactive rock will be placed in the BRSF and more acidic drainage report to Pond PD-7. The problems of solid settling in the HLF detention pond during operation will become increasingly worse and the company will need to consider a dedicated lime plant.

Arguably, a lime plant with a clarifier should be considered earlier, when combined flows from pit dewatering and the BRSF toe drain approach 300-400 m^3/hr, and combined aluminum and iron concentrations reach 30-40 mg/L. At these loads (~10-20 kg/hr), solids management is difficult without a mechanical system that incorporate addition of coagulants/flocculants and use of clarifiers or lamellar systems.

With increasing mine life, there will be an even greater amount of reactive rock added to the BRSF, particularly sulfides originating from the Lower Volcanics. **I argued above that this will create problems for the development of an effective cover at closure, and that it would be preferable to segregate this rock and eventually backfill it in a mined out pit.** This option may not be considered necessary when life of mine is limited to 10 years, but it may become inevitable if it extends for more years. In that case, it would be preferable to implement a program of rock segregation as early as possible. In practice, rock should be segregated based on Total Sulfur content[4] and only very low S rock should be placed in the BRSF. As operations reach the Lower Volcanics and mining expands well into this zone, new methods of mineral processing should be used to extract gold from high S rock (when heap leaching becomes increasingly problematic).

[3] Mine Environment Neutral Drainage (MEND). 2015. Report 2.36.1b - In-Pit Disposal of Reactive Mine Wastes: Approaches, Update and Case Study Results - October 01, 2015.250 p.

[4] If supported by humidity cell test results

3 Heap Leach Rinsate and Drain down

Operation of the heap will mobilize a number of toxic metals/metalloids and create new toxic compounds. Cyanide will dissolve and form soluble compounds with metals like cobalt and mercury. Additionally, antimony, arsenic and selenium may be dissolved. Sulfide and selenium minerals will react with cyanide and form selenocyanate and thiocyanate. Ammonia will be generated by the decomposition of cyanide and will remain in the leach solution or in the heap solids[5]. **All these compounds will build up in the leach solution or in solids in the heap, as the leach solution is continually recirculated on the heap. We need to know how compounds like arsenic, mercury or thiocyanate will be removed when the heap is decommissioned.**

Some of these compounds, like selenocyanate or thiocyanate will probably require biological destruction[6]. Cobalt will probably be present as a cyanide complex and its removal will not be the same as if it were a dissolved metal. Mercury is very difficult to remove to very low concentrations, typically requiring treatment with specialty organosulfide reagents. Other compounds have their own specific treatment requirements.

Part of the problem is that rinsing the heap will probably remove most of the toxic compounds in the heap porewater, but it will not deal with compounds that are adsorbed onto heap solids like ammonia or thiocyanate. The latter will be released gradually, slowly for several years after the heap is rinsed. It is important that they are removed from the heap discharge before it is released to the environment.

The ESIA indicates that, post-closure, these contaminants will be removed through a passive treatment system constructed in one of the ponds below the heap, but no design information is provided. **A conceptual design and design criteria for this passive treatment system are required to determine if this option will produce an effluent that is safe to discharge.**

By far, the preferred solution is to omit addition of sulfide minerals on the heap and process these minerals in a different manner. This is especially appropriate if new targets are found in the Lower Volcanics and mine life is likely to be extended.

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[5] Ammonia will also be lost by volatilization during operation of the heap.

[6] For example, see Given, B. and S. Meyer. 1998. Biological treatment of tailings solution at the Nickel Plate Mine. BC Technical and Research Committee on Reclamation, Proceedings of the 22th BC Mine Reclamation Symposium, Penticton, BC, Sept 14-17. p. 157.170. At that mine site, mill process water was recycled with reclaim water (tailings pond supernatant), resulting in a gradual buildup of thiocyanate. At closure, thiocyanate concentrations in reclaim water were 1.4 g/L.

4 Water Quality Predictions

I do not have confidence in the predicted chemistry of water draining the toe of the BRSF, nor do others in the review team. This drainage is predicted to be moderately acidic and contain low contaminant concentrations, yet the humidity cell test work indicates that some of the Lower Volcanic material is extremely reactive and will release high levels of acidity, aluminum, iron and sulfate. The complex geology of the ore body suggests that reactive and non-reactive rock may be mined throughout pit development and that the reactive rock will be distributed throughout the BRSF, rather than distributed simply and in a manner that can easily be isolated by encapsulation.

It is expected that actual BRSF toe drainage chemistry at closure will have higher total concentrations of metals (especially aluminum and iron) and sulfate, and possibly the presence of additional contaminants. This was acknowledged by Sovereign when they revised the predicted BRSF drainage by incorporating data from Site 13 and 27. **Underpredicting metal concentrations is a serious problem for the design of passive treatment systems because metal loads usually determine the type of system used for water treatment.** For instance, a passive treatment system that can tolerate 1-3 mg/L dissolved aluminum and iron may be unsuitable for streams that contain >10 mg/L, and an incorrect prediction may result in the selection of an inappropriate treatment system.

5 Post-Closure Passive Water Treatment System

The previous discussion of acidic drainage generated during operations indicated that a lime-based treatment plant should eventually be developed to neutralize acid water and manage the resulting metal precipitates. The following discussion pertains to passive treatment systems proposed to deal with post-closure mine waters.

5.1 BRSF Toe Drain

A conceptual design for a passive treatment system is proposed to treat BRSF toe drain discharges after mine closure. **The proposed passive treatment system is inappropriate.**

The ARD Management Plan states that Anoxic Limestone Beds[7] will be used to neutralize BRSF toe drainage, but no the conceptual system design presented in Sovereign's December 2015 memo does not include ALDs. That memo shows that BRSF drainage will first report into a pond (PD-8), and then to a biochemical reactor (BCR) designed for nitrate reduction.

[7] Conventionally, Anoxic Limestone Drains, ALDs

A BCR is inappropriate to treat acidic, metal-laden water. This is because biological processes in a BCR function at neutral pH, not acidic pH. Under acidic conditions, microbes in the BCR will not remove nitrate. Additionally, the design (a system with an organic matrix that supports nitrate reduction) is inappropriate to treat acidic waters that contain metals because they will precipitate within the BCR and plug it quickly. This will preventing water from flowing evenly through the system and treatment performance will quickly deteriorate.

Conceptually, a passive treatment system that receives acidic mine drainage must have an upstream unit that neutralizes water pH and removes the bulk of metals that are soluble at acidic pH. At Amulsar, this means the first unit should be a limestone-based system that neutralizes water pH and removes aluminum and iron. For the predicted flows, a Vertical Flow Wetland (VFW) is the best technology than for that purpose[8]. VFWs can accept higher flows than ALDs and can neutralize more acidic water and remove higher concentrations of aluminum and iron. Additionally, VFWs are now being automated for regular flushing of accumulated sludges, thereby increasing their reliability in a closure scenario. Given the uncertainty in the final aluminum and iron concentrations in the BRSF toe drain at closure, using a VFW would be a more suitable passive treatment technology than the currently proposed ALDs.

Neutralization of acidic water and removal of aluminum and iron are only the first steps in treating BRSF toe drainage. Other contaminants, like cobalt, lead, sulfate or zinc need to be removed. In Sovereign's design memo, manganese removal beds are designed to remove manganese and, subsequently, adsorb cobalt, zinc, lead and nickel. **These beds will not achieve the desired metal removal because influent manganese concentrations are too low.** Instead, sulfate-reducing BCRs should be sized to remove these contaminants, as well as sulfate, downstream of VFWs or other technology that neutralizes water pH. In addition, limestone drains should be installed downstream of the sulfide scrubbers and polishing ponds to remove manganese.

In the case of BCRs designed to remove sulfate, Sovereign needs to demonstrate how they will achieve their discharge goals in the long-term because such systems have never been designed. It is insufficient for Sovereign to show sulfate removal rates and size their system accordingly. Their conceptual design also need to demonstrate that these rates will be maintained in the long-term (i.e., decades and centuries) and that sulfate will be permanently retained in their systems.

The proposed polishing step (sulfide scrubber and BOD removal) need to be demonstrated, particularly the long-term performance and viability of the sulfide removal process.

[8] Skousen, J., Zipper, C.E., Rose, A. Ziemkiewicz, P.F., Nairn, R. McDonald, L.M. and Kleinmann, R.P.L. 2017. Review of Passive Systems for Acid Mine Drainage Treatment. Mine Water Environ 36: 133. doi:10.1007/s10230-016-0417-1

These comments are predicated on the assumption that predictions of the BRSF toe drain are reasonably accurate. However, other members of the review team have cast doubts on this assumption, and this increases the risk that the proposed passive treatment systems will fail to treat water adequately. Additionally, the proposed systems do not provide any flexibility to accommodate for any possible mine expansion. Their design should be revised to account for these two possibilities.

The proposed passive treatment system will accumulate all the metals that it retains. Eventually, this accumulation of metals will begin to interfere with the proper function of the system. Additionally, the organic matrix in the BCR will become depleted and need to be refurbished. Experienced practitioners can readily recognize these developments and prescribe corrective actions, but this is not the case for inexperienced field staff, who will be unable to distinguish a system malfunction from a normal development that requires maintenance. This is especially important at a remote site like Amulsar, where no one can provide effective diagnostic of malfunction and develop appropriate corrective action. This situation increases the risk of downstream environmental impacts.

Lydian needs to demonstrate that these systems can be operated reliably year-round for decades, and that staff under their authority will be sufficiently competent to maintain these systems, identify malfunctions and develop appropriate corrective actions. **The company also needs to demonstrate that it has the resources to operate and maintain these systems for at least 100 years, which is, at a minimum, how long they are likely to be operated.**

5.2 HLF Drain

Lydian provided no design for a passive treatment system to treat post-closure drainage for the HLF. Drainage from the HLF will contain several contaminants in drain down, including ammonia, arsenic, cobalt, mercury, selenocyanate and thiocyanate. All these contaminants respond to specific treatment processes, some of which are mutually incompatible (i.e., the removal of ammonia and thiocyanate are oxidative processes that require oxic conditions, whereas cobalt removal requires anoxic conditions).

Ammonia, selenocyanate and thiocyanate will continue to be released for many years after the heap is rinsed because they will retained in the heap solids and will be released slowly over time. There is no viable chemical process for the destruction of thiocyanate. It removal has only been demonstrated in the biological treatment plants at at Beal Mountain and Nickel Plate Mine[9], but never in passive treatment systems. Additionally, there is no published method for removal of selenocyanate, though this compound is known to occur at a number of mine sites.

[9] Despite closing in 1996, the Nickel Plate Mine still produces ammonia and thiocyanate in tailings pond seepage, indicating that they are released slowly by these solids long after mining operations shut down.

Lydian needs to show how a passive treatment system receiving drainage from the closed heap will be able to remove these toxic compounds.

In many regards, the problems associated with the detoxification and remediation of the spent heap would be eliminated if sulfide minerals (largely from the Lower Volcanics) were not placed on the heap. This would eliminate the long-term problems with acidification of the heap, as well as formation of selenocyanate and thiocyanate. Lydian should reconsider applying sulfide minerals from the Lower Volcanics on the heap and avoid the potential long-term costs and liabilities associated with treatment of heap drainage.

5.3 Closed Pit Overflow

There are no plans to treat the acidic drainage discharged by the closed pits. Instead, pit water is predicted to infiltrate the pit bottoms and seep to springs that are already acidic. There is no contingency plan in case the pit bottoms and walls are sufficiently tight that the pit retains water and creates a pit lake. As a contingency, the proponent should identify a remedy for treating acidic pit lake overflow, either through an active or passive treatment system.

6 Conclusions

I have evaluated the treatment systems proposed during the operation of the Amulsar project and after its closure for. There are problems with all the systems proposed by the mining company, some more important than the others.

The collection and treatment (through lime addition) of waters from pit dewatering and the BRSF toe drain will work well in early years (Year 1-5), but will progressively deteriorate because the volumes of water and metal mass loadings will increase over time. At some point after Year 5, the mine should decide if it should build and operate a stand-alone lime treatment plant, especially if flows reach 300-400 m^3/hr and combined aluminum and iron concentrations reach 30-40 mg/L. One trigger favouring this decision might be the discovery of new deposits that will extend mine life past the planned 10 year life and increase flows beyond the above thresholds.

The proposed passive treat systems for the closed Amulsar mine will not fully detoxify water. The conceptual design proposed by Sovereign will fail because it is not designed to treat acidic drainage that contains elevated aluminum and iron concentrations. An alternative is proposed that has been proven in this application. A passive treatment system is also proposed for the HLF drain-down, but no design has been proposed. **This is unacceptable because several toxic compounds, including ammonia, arsenic, mercury, thiocyanate and others, will be present for many years in the discharge from the closed HLF and will need to be treated.**

André Sobolewski, Ph.D.
Gibsons, BC | 604.240.8845 | andre@clear-coast.com

There is a broader concern that, with the current proposed mine plan, ARD will be generated for centuries after the mine is closed. The highly-reactive nature of rocks in the Lower Volcanics means that ARD generation from the BRSF is a significant risk, even with the proposed encapsulation and soil cover. A more prudent approach would be to segregate waste rock on the basis of Total S (as a proxy for NAG/PAG rock) and only place low S rock in the BRSF. High S/PAG rock should be placed in a special repository next to one or more of the pit, with the aim to backfill them in the mined out pits and flood them to prevent ARD generation. Martin (2011) presents several accounts of its practice[10]. Additionally, Lydian International should consider changing its approach to mineral processing as it reaches near the Lower Volcanics if additional exploration indicates that there is more economic gold at depth. This is because there is much more sulfide in the Lower Volcanics and they impact as much on mineral processing and gold recovery as they do on the risk of long-term ARD generation.

The Amulsar project is the first of its kind in Armenia. Everyone involved with this project should ensure that it leaves a positive legacy for the country, rather than a negative legacy of long-term ARD generation that could damage some of the more beautiful parts of the country. I hope that my review and comments will help to guarantee the former rather than the latter.

Respectfully,

Clear Coast Consulting, Inc.

André Sobolewski, Ph.D.

7 Author Qualifications

Dr Sobolewski has 27 years of professional experience with the assessment of environmental impacts from proposed mining developments and the design, construction and investigation of mine water treatment systems. He has been involved in over 50 mine water treatment projects, including the design of full-scale treatment plants at Minera Yanacocha (Peru), treatment wetlands at Minera Antamina (Peru), Campbell Mine (Ontario), confidential abandoned mine (Colorado), and design of the passive bioreactor at the Tulsequah Chief Mine (BC). He has

[10] Martin, T.E. 2011. Mine waste management in wet, mountainous terrain: Some British Columbia perspectives. Part II – Creating, managing and judging our legacy. Proceedings Tailings and Mine Waste 2011, Vancouver, BC.

worked at several gold mines, including the heap leach operations at Beal Mountain and Brewery Creek Mines and at Minera Yanacocha, and open pit and underground operations at Campbell, DeLamar, Golden Sunlight, Musselwhite, Nickel Plate, Red Lake Mines. Dr Sobolewski co-authored a number of authoritative works, including the *Technical Guide for the Environmental Management of Cyanide in Mining*, for the Mining Association of BC, the *Guidelines for the Prediction and Mitigation of Potential Direct Environmental Effects from Effluent and Waste Rock Management of Major Hard Rock Mining Projects* for YESAB. André taught four courses on the biological treatment of contaminated mine water and he will teach the course Advanced Passive Bioreactor Design and Operation at the upcoming IMWA 2017 Finland conference.

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