APPENDIX H5

GROUTING PROPOSAL PEER REVIEW

BIRD IN HAND GOLD PROJECT

MINING LEASE PROPOSAL MC 4473

TERRAMIN

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TECHNICAL MEMORANDUM

DATE 11 December 2017 **REFERENCE No.** 1659870-001-TM-Rev0-9000

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CC Gary Chapman

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BIRD-IN-HAND GOLD PROJECT – EXTERNAL REVIEW – PROPOSED GROUTING PROGRAMME

1.0 INTRODUCTION

This technical memorandum summarizes Golder Associates' (Golder's) review of the document "*Grouting for Groundwater Control*" submitted by MultiGrout® Australia Ltd. (MultiGrout®) on 12 February 2017 to Terramin Australia Ltd. (Terramin) and provides comments with respect to the requested scope of work outlined in the document *"Bird in Hand Gold Project – Groundwater Management – Peer Review Scope"* Rev.A, subsequent email correspondence, and our email proposal dated 21 August 2017.

2.0 BACKGROUND

Terramin is proposing to advance development of the Bird-in-Hand Gold Project (BIH), a steeply dipping, reef gold deposit hosted in the Brighton Limestone (Marble) near the township of Woodside, SA, in the Adelaide Hills. Details regarding the BIH project and the geological/geotechnical setting of the proposed mine are provided in the Terramin (2017) scope and MultiGrout® (2017) memorandum – some of which, for reference purposes, are repeated below.

The mine is located in the Woodside goldfields, and is one of many small mines originally mined in the late 1880s, then again as recently as the 1930s, but was abandoned around this time due to significant water inflows. Terramin is proposing to re-open the mine using cut and fill methods to extract the known resource.

In general, decline excavation and approach development is planned to be carried out in the footwall, within the Tapley Hill Formation, a low conductivity unit with an average hydraulic conductivity of 3.5×10^{-7} m/sec (i.e., 2 to 3 Lugeon units). Vertical infrastructure, including vent raises, shafts, and emergency egress, as well as access and ore drives are planned to be developed in proximity to and potentially through a fractured zone in the hanging wall within the Tarcowie Siltstone, with reported hydraulic conductivities values ranging upwards of approximately 3×10^{-5} m/sec (or > 200 Lugeon units). The Tarcowie Siltstone between the fractured zone and the Brighton Marble is interpreted to have a hydraulic conductivity approximately between that of the Tapley Hill and the fractured zone, while the Brighton Marble is anticipated to have a low conductivity of approximately 6×10^{-7} m/sec (or 4 to 5 Lugeon units). A conceptual model of the proposed BIH setting is provided in Figure 1 of the MultiGrout® (2017) document.

3.0 DISCUSSION

In general, given the information available at the time of preparation of this memorandum, Golder agrees with the proposed pre-excavation grouting approach proposed by MultiGrout®. As such, the discussion provided below aims to supplement the knowledge shared by MultiGrout®, and to provide additional support to the claims substantiated in their memorandum.

3.1 Effectiveness

Golder and MultiGrout® appear to share many of the same experiences with respect to percent effectiveness of pre-excavation (or cover) grouting activities. We agree that given the indicated ground conditions, it is reasonable to expect a 90% (or greater) inflow reduction using cementitious grouts, assuming good practice and adequate resources. Examples of highly effective cover grouting activities achieved using modern, systematic, drilling and grouting techniques are presented in the following references.

- Civil tunnelling, pre-excavation grouting techniques have been well documented by Scandinavian and European agencies, including:
    - Tolppanen, P., and Syrjänen, P., 2003. *"Hard Rock Tunnel Grouting Practice in Finland, Sweden, and Norway, Literature Study"*, Finnish Tunnelling Association, MTR JULKAISUT, N:RO 1, 84 p.
    - Hognestad, H.O., Fagermo, J.I., Kveen, A., Backer, L., Grøv, E., Frogner, E., and Aarset, A., 2011. *"Rock Mass Grouting in Norwegian Tunnelling"*, Publication No. 20, Norwegian Tunnelling Society, Oslo, 108 p.
    - Garshol, Knut F. 2003. *"Pre-Excavation Grouting in Rock Tunneling"*, MBT International Underground Construction Group, BASF (formerly Degrussa Construction Chemicals), Switzerland, 140 p.

  A relevant example of success using techniques similar to those outlined by MultiGrout® is provided in Section 10.5 of Garshol (2003). The Bekkestua Tunnel is a short tunnel (705 m long, cross section 68 m^2) located in a suburb of Oslo in a semi-agricultural area. The limit of water ingress into the tunnel was set as maximum 2 l/minute per 100 m of tunnel length. Where water ingress was measured at more than 5 l/min per 21 m length probe hole, cover grouting was carried out with Ordinary Portland Cement (OPC) which is equivalent to Type GP cement. Where water ingress was less than 5 l/min per 21 m of probe hole, injection was carried out with microfine cement. The resulting measured total water ingress to the tunnel at the end of the excavation period was 0.7 L/min/100m; the largest rate of leakage being 1.7 l/min/100 m tunnel length in a section where only OPC had been used.

- From our own experience, during the winter of 2015/16, Golder designed and supervised cover grouting activities for the Upper Lillooet Hydroelectric Project through an unconsolidated deposit of volcanic avalanche debris and pumice where inflows of greater than 150 L/min/100 m were reduced to less than 2 L/min/100 m using a combination of Type HE and ultrafine based cementitious grouts, a reduction in inflows of approximately 98%:
    - Bonin, G., Lillico, B., Robson, O., de Batz R., and Moali, S., 2017. *"Part 2: Cover grouting through unconsolidated deposits at the Upper Lillooet Hydroelectric Project, Pemberton, BC, Canada"*, Proc. of the 2017 World Tunnelling Congress, ITA-AITES, Bergen, Norway.

3.2 Groutability vs. Cement Type Selection

MultiGrout® state that the use of general purpose, Type GP, cement should provide a reasonable expectation of achieving a 90% inflow reduction. While this seems possible, it is worth considering that Type GP cements have a percent finer than D_{95} of approximately 50 microns while high early strength, Type HE cements have a D_{95} of approximately 30 microns.

Fracture aperture distributions can be obtained by a number of means including optical or acoustic televiewer profiling, or more simplistically, when hydraulic conductivity test information is available, by determining the average aperture opening dimension over a given diamond core interval after the procedure presented by Louis (1969) as follows:

$$k = \frac{a^3}{12s}$$

where:

k = hydraulic conductivity (m/sec);

a = aperture (m); and

s = average spacing (m) between discontinuities in the tested interval, i.e. 1 / (fracture frequency).

The groutability of a rock mass can then be expressed by comparing the ratio of fracture apertures to cement particle size via the equations presented in Karol (2003):

$$GR = \frac{width\ of\ fissure}{(D_{95})\ grout}$$

Grouting is considered to be consistently possible if the groutability ratio (GR) is > 5, not feasible if GR < 2, and potentially feasible if GR is between 2 and 5.

Thus, Type HE cements will permeate finer aperture discontinuities, reducing residual hydraulic conductivity and potential inflows. It is because of this that, for an incremental increase in cost of a few pennies per litre of cementitious grout injected, we suggest that high early strength, Type HE cements, with a D_{95} of approximately 30 microns be used for the proposed grouting programme instead of Type GP cement.

Furthermore, it should be noted that many highly effective grouting programmes involve the use of finer grinds of cement including micro- or ultrafine cements, with percent finer than D_{95} particle sizes of <20 microns and <10 microns, respectively. Suitable examples of such grinds of cement available from Cement Australia (imported from France) are Spinor A20 and Spinor A12, respectively, but these cements range in cost per litre injected from 6 to 12 times that of Type HE cement.

Lastly, while it is not considered necessary nor practical for the proposed BIH mine development purposes, other solution based grouts such as colloidal silica could reduce residual groundwater inflows into a tunnel to much less than 2 L/min/100 m. The use of such injection materials is gaining acceptance in the civil tunnelling industry, where long term maintenance costs warrant the use of such materials to achieve extremely dry conditions. It is important to recognize that the injection materials and techniques exist to achieve whatever inflow criteria is ultimately set.

3.3 Methodology

The methods of probe hole drilling, deciding whether or not to grout based on intersected inflows, and thereafter carrying out cover grouting activities in advance of excavation described by MultiGrout® are common industry practice. Nevertheless, cover grouting is an iterative, continually improving process in which, flexibility of approach must be maintained.

Additional, more specific comments on good grouting practice, in no particular order, are provided to supplement those provided by MultiGrout® as follows:

- It should be emphasised, that regardless of whether or not water is anticipated to be intersected, probe holes should be systematically drilled ahead of all excavations in increments over the total depth of proposed excavation without exception. The orientation and location of these probe holes should be planned such that they can be incorporated into the subsequent cover grouting program as primary grout holes, if necessary.

- For access drives, the number of probe holes to be drilled should be based on the dimensions of the heading to be excavated. While three may be sufficient for headings of less than 4 m width and height, large-scale cut and fill mining operations typically work with headings of 6+ metres width. Additional probe holes, upwards of 6 to 8 in total may be required.

- For ore drives, we agree that additional effort should be dedicated to assessing ground support requirements for the hanging wall, and that the costs and benefits of these efforts, such as installing cable bolts within the previously grouted holes versus combining hollow, groutable rock reinforcement (either spiling or canopy tubes) should compared with one another.

- Ungrouted exploration drill holes beneath the water table and through proposed mine headings present a particular hazard to mining operations depending on the ground conditions (rock mass quality) the ungrouted hole has intersected. In good (or better) rock mass quality, it may be possible to use Mineright jumbo-installed packers or other, spear-shaped malleable rubber, jumbo-installed packers such as those shown below in Plate 1. In our experience, unless secured in place at the collar (i.e., with J-bolts and chains) such mechanical -like packers are only safe to withstand pressures of 600 psi (~40 bar).

- In fair (and, in particular, worse) rock mass quality, when it is unknown as to whether or not a particular exploration drill hole has been properly abandoned and filled with cementitious grout, it may be necessary to plan exclusion zones surrounding such boreholes and/or establish contingency measures including emergency bulkhead construction preparedness.

- Where necessary, as correctly described by MultiGrout®, probe/cover hole drilling and grouting will be carried out through steel standpipes sealed into an oversized hole by a grout placed in the annulus between the pipe and the rock. Standpipes should be thick-walled, extra-strong (i.e., Schedule 80). One end of the standpipe should be BSP threaded or Victaulic-grooved. The annular grout should be a non-bleed, slightly expansive cementitious casing grout such (such as Celroc-P from Minova) which sets around the pipe to form a strong anchorage and a seal. Standpipes should be approximately 1.5 m to 4.5 m in length, depending upon encountered ground conditions and the anticipated grouting pressure. Prior to commencing probe hole drilling all standpipes should be pressure tested with biodegradable, fluorescein dyed water to a minimum of 6 bar above the proposed injection pressure, and re-grouted, if they fail their pressure test, with single-component, water-reactive polyurethane resin to decrease wait time.

Plate 1: Spear-Shaped, Jumbo-Installed, Malleable Rubber, Borehole Packer

- When selecting drilling jumbos, we suggest that in addition to the use of rod handling carousals, that the stiffest possible and most easily handled rod/coupler/bit combination be acquired. Recent discussions with Canadian tunnelling contractors has indicated that the use of T45 rods with a nominal 76 mm diameter bit has been gaining acceptance in the hydroelectric, civil construction industry as the preferred combination. Even with these measures, it is because of potential hole deviation, that layouts for cover grouting programs are generally “tighter” (i.e., with planned grout hole toe spacings as close as 1.5 m to 2.0 m) than those typically used on surface, dam-foundation grouting programs.

- Given a desire to balance tight grout hole toe spacings with few drill set-ups, and without paying particular attention to the development dimensions nor ground support requirements, it is suggested that cover lengths with 6 m overlaps can be drilled to:

  - 20 m to 30 m within the very poor to poor quality; or

  - 30 m to 45 m within fair quality rock masses.

- To decrease batch time and increase productivity, we suggest that an electric hydraulic, minimum 400 L capacity, high-shear colloidal mixer, 600 L capacity agitator and pump combination be utilised for all grouting activities. An example of a typical grout plant set-up is shown in Plate 2. While a dual-acting, double plunger piston pump is shown in the photograph, helical screw, positive displacement Moyno (Mono) 3L8 or 6M6 pumps rated to injection pressures of 15 bar and 30 bar, respectively, can be used at shallower depths initially during ramp development to improve productivity. As pointed out by MultiGrout®, it is not unheard-of for one mixer to supply multiple agitators and pumps, and palletised batch plants can be fabricated onto much smaller platforms than that shown in Plate 2.

- In general, the unit rates, productivity, potential schedule impacts, etc. provided by MultiGrout® are considered to be reasonable for the level of information available. With improved understanding of the mine access and ore drive layout, as well as potential lengths of development requiring pre-excavation grouting and/or hanging wall support, a more definitive cost estimate based on potential grout take / metre length of primary and split-spaced secondary grouting sequence plus contingencies can be developed. Such a cost estimate would obviously benefit from a more detailed, three-dimensional understanding of geological, geotechnical and hydrogeological parameters being developed in subsequent stages of design.

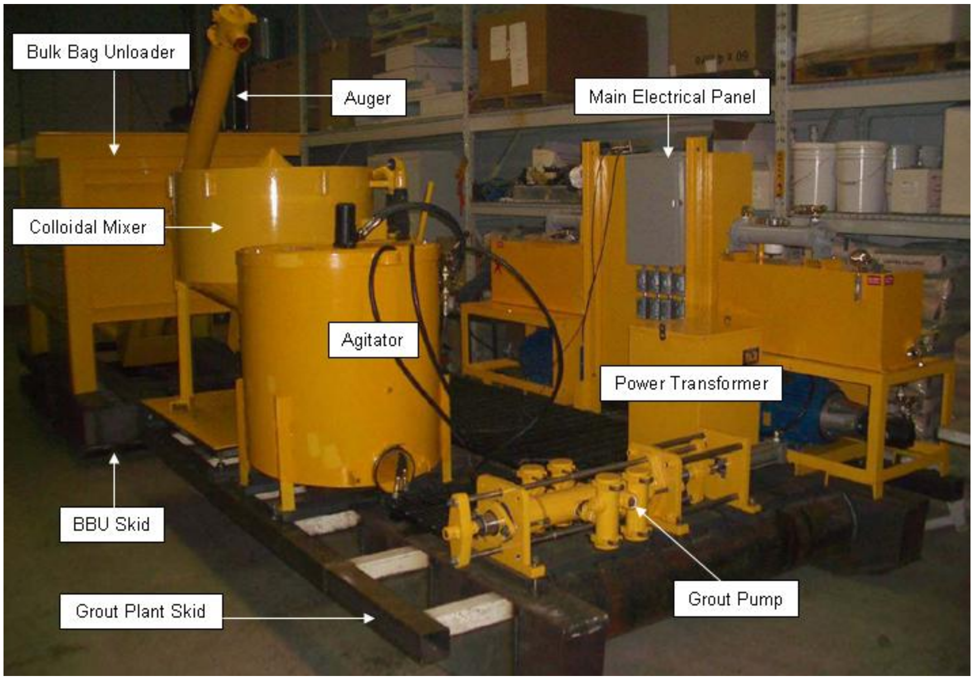

Plate 2: Skid-Mounted Colloidal Mixer, Agitator, and Grout Pump

- We support the notion of always developing multiple work fronts such that pre-excavation grouting activities can be carried out “off line” of more important production activities. This typically means that a team of trained staff dedicated solely to drilling and grouting activities is required or that, at a minimum, all crews have a fundamental understanding of what is required and are supported by one or two individuals with an expert level of experience, who are tasked with logistics, quality control and data management pertaining to grouting activities.
- Lastly, while we agree with MultiGrout® that systematic, pre-excavation grouting with cementitious grouts is the preferred approach, one cannot plan for all eventualities. As such, when preparing for cover grouting operations, we suggest that some amount of post-excavation grouting should be anticipated. Such activities would include the capital purchase and training of staff miners in the use of single-component, water-reactive, polyurethane resins and associated batching, injection with paint sprayer-like, air-pneumatic, piston pumps, and maintenance of such equipment.

3.4 Environmental Considerations

While not specifically discussed in the MultiGrout® (2017) technical memorandum, we understand that the following topics have been assessed by others in separate reports. Therefore, the topics discussed below are only provided in light of their importance with respect to the proposed approach.

- No discussion of pre-excavation ground improvement is complete without a full understanding of the context in which the proposed works are required. Regulatory requirements for allowable impacts to the environment vary by jurisdiction. Discharge water quality, rate and total quantity within specific periods and in specific seasons may all be all be regulated. Cover grouting activities are not necessarily required when the combination of underground sump size, power and pumping capacity, surface water storage, water treatment and permitted off-site discharge can be optimized.

- The impacts of underground mining activities on regional groundwater chemistry and water levels needs to be appreciated and planned for. Pre-excavation grouting will not stop the flow of groundwater – it will only reduce the likelihood of it entering the workings. Mining activities will draw regional groundwater levels down. The acceptable impacts are most likely a permitting requirement. The impact of residual inflows into the workings on the surrounding environment may still need to be demonstrated by improving the regional hydrogeological understanding through investigations. Such investigations may include regional pumping or injection well testing and observations of pressure or water level recovery to existing conditions. This will almost certainly entail three-dimensional groundwater modelling supported/calibrated by updates based on actual conditions encountered during mining activities. Such modelling may also indicate what residual inflow, in terms of L/min/100 m length of tunnel is required to proceed, and that will dictate pre-excavation grouting materials/effort required.

- As result of grouting operations, the inflowing water is likely to have a pH ranging between 12 and 14. Water pumped to surface, like all mine waters, will need to settle and be treated – with pH typically lowered using carbon dioxide bubblers.

  Cut and fill mining operations, depending on backfill chemistry and properties will also have an influence on the geochemistry of residual inflows. Cementitious and potentially acid generating materials interact with one another. Long term leach testing of proposed backfill materials will improve the understanding of water treatment requirements.

  Neglecting to think through the process of operational water quality, water treatment capacity and discharge licensing requirements has been known to force some underground mining operations to shut down.

4.0 CLOSURE

In conclusion, we believe that MultiGrout® has prepared a fair, reasonably detailed approach based on the information most likely available to them, and we believe that the level of professional judgement and expertise they will bring to Terramin will be beneficial in developing a more comprehensive grouting strategy as experience is gained at the Bird-in-Hand Gold Project.

We trust that the information provided satisfies your current project requirements. If you have any comments or concerns, please do not hesitate to contact us.

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