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# Vuggy and cavernous rock mass conditions: implications for the early detection, management, ground support and development of tunnels

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## Abstract

*Development and mining production activities in and around existing or historical mining voids routinely occurs in underground mining practices when the nature and location of the void is well understood. However on rare occasions, mining operations can be faced with naturally occurring vuggs or voids within rock masses which are large enough to present significant development, safety and productivity issues. The Regis Resources-owned Garden Well South underground mine operation first encountered large, naturally occurring cavities or voids in March 2022, and this impacted on the development and therefore the mining schedule. The voids could range up to several metres in width and height, and were often cylindrical in shape and up to 20 m in length. Furthermore, the presence of water was also a feature requiring significant effort to manage through dewatering activities. The cavities and voids are partly coincident with the Garden Well South orebody. This triggered the development of a framework of management plans and development and mining practices for the successful return to productive mining activities. Development and ground support practices were adapted to allow the safe and successful resumption of mining.*

*Garden Well is part of the Duketon South Gold Operation, and is located near Laverton, Western Australia. The Garden Well South underground mine commenced underground construction in 2021, and declared commercial production in Q4 FY'23 following several years of open pit mining. The cavities encountered were large and frequent enough to cause delays resulting in loss of development productivity, raise implications for development drive stability, and ultimately impact on the drilling and blasting of stopes.*

*Significant adaptation of ground support and development practices were undertaken to ensure that the resumption of mining could occur in a safe and efficient manner. This has included detailed evaluation of the presence of vuggs, determining the load-demand requirements of the rock mass when voids were present, and trialling and ultimately adopting appropriate surface support and reinforcement practices accordingly.*

*Furthermore, in order to create a safe system of work, the mine embarked upon developing a void management plan for the overall centralising of documents and procedures developed for managing interactions with voids and cavities, and to articulate actions, timing, and roles and responsibilities in order to be effective. The early strategies for the detection and management of naturally occurring voids zone included a trigger action response plan document for immediate and tactical management of voids in development, close engagement with the mine geological team to develop a vugg/void model, contractor engagement to gather input into strategies and gain confidence in the management plan, and modification of development and ground control practices, to name a few. This paper describes the processes followed to ensure that a safe and effective resumption of mining activities could occur at the Garden Well underground mine with a specific focus on surface support and reinforcement practices for securing development in vuggy and void-affected rock masses.*

**Keywords:** *vugg, void, void management plan*

# 1 Introduction

Regis Resources Ltd is a high-margin gold producer and explorer with over a decade of consistent production and reserve growth underpinned by continued exploration success and targeted acquisitions. The Duketon Greenstone Belt is located in the North Eastern Goldfields of Western Australia (WA), and consists of the Moolart Well, Garden Well and Rosemont gold mining centres.

The Garden Well South (GWS) deposit is located approximately 90 kilometres north of Laverton in WA, and forms part of the Regis Resources Ltd Duketon Gold Project. At the commencement of development, the underground deposit had an ore reserve of 280 koz for a mine life of 60 months. Underground development commenced in March 2021, and first production occurred in Q2 FY'23.

# 2 Site geological setting

The geology of GWS consists of a sequence of folded sedimentary and volcanic rocks (see Figure 1). The sequence can be differentiated from east to west into fine-grained siltstones, lapilli and tuff volcaniclastics, sedimentary breccias, black shales, banded iron formation (BIF), chert, interbedded chert/shale and a footwall basalt unit. All of the units strike north-northwest, at approximately 340–350°.

The siltstones are typically fine grained and occasionally grade into coarser quartz-bearing sandstone. The siltstones are predominantly sericite-chlorite-carbonate altered and are often competent. The volcaniclastics can appear quite similar to the siltstones, however, they contain clear clasts of volcanic origin. Similar to the siltstones, the volcaniclastics are dominated by sericite-chlorite-carbonate alteration. Within both units, the bedding orientation has been realigned with the regional foliation, which is the result of the Garden Well Shear Zone. This can result in the units being schistose.

The sedimentary breccia is dominated by chert clasts within a fine-grained matrix. It is often interbedded with the volcaniclastics, BIF and shale. The clasts often display a preferred orientation, aligning with the regional foliation. As well as this, the unit is brecciated and often quite broken.

The BIF is very high strength and competent. Magnetite and hematite define the bedding planes within the unit, resulting in a colour variance from dark grey to red. The chert, which is the primary host to mineralisation at GWS, is dominated by siderite alteration and is also very high strength. Unlike the lower-strength sediments and volcaniclastics in which the fabric has conformed to the regional foliation orientation, within the competent BIF and chert the regional foliation can be observed cross cutting and displacing the bedding planes.

Some of the shales are carbonaceous and graphitic in nature. As is often the case with shales, they are of lower strength and fissile. The shales are often interbedded with chert in the footwall position prior to intersecting the footwall basalt unit. When interbedded with the chert, the shales can occasionally be host to mineralisation.

The footwall basalt (mafic) is typically fine grained and strongly sericite-chlorite-carbonate altered. The unit is often interbedded with shale, and occasionally displays fuchsite alteration adjacent to the shale contacts. The mafic is strongly foliated, which results in the rock mass often being broken along the foliation planes.

The folding at GWS is tight and plunges approximately 20° to the south-southeast. The mineralisation is primarily present within the western limb of the syncline, within a steep shear zone (60–80° E). The primary host to mineralisation is the siderite altered chert. The mineralisation is present as pyrite beds and veinlets, reaching concentrations of 10–20%.

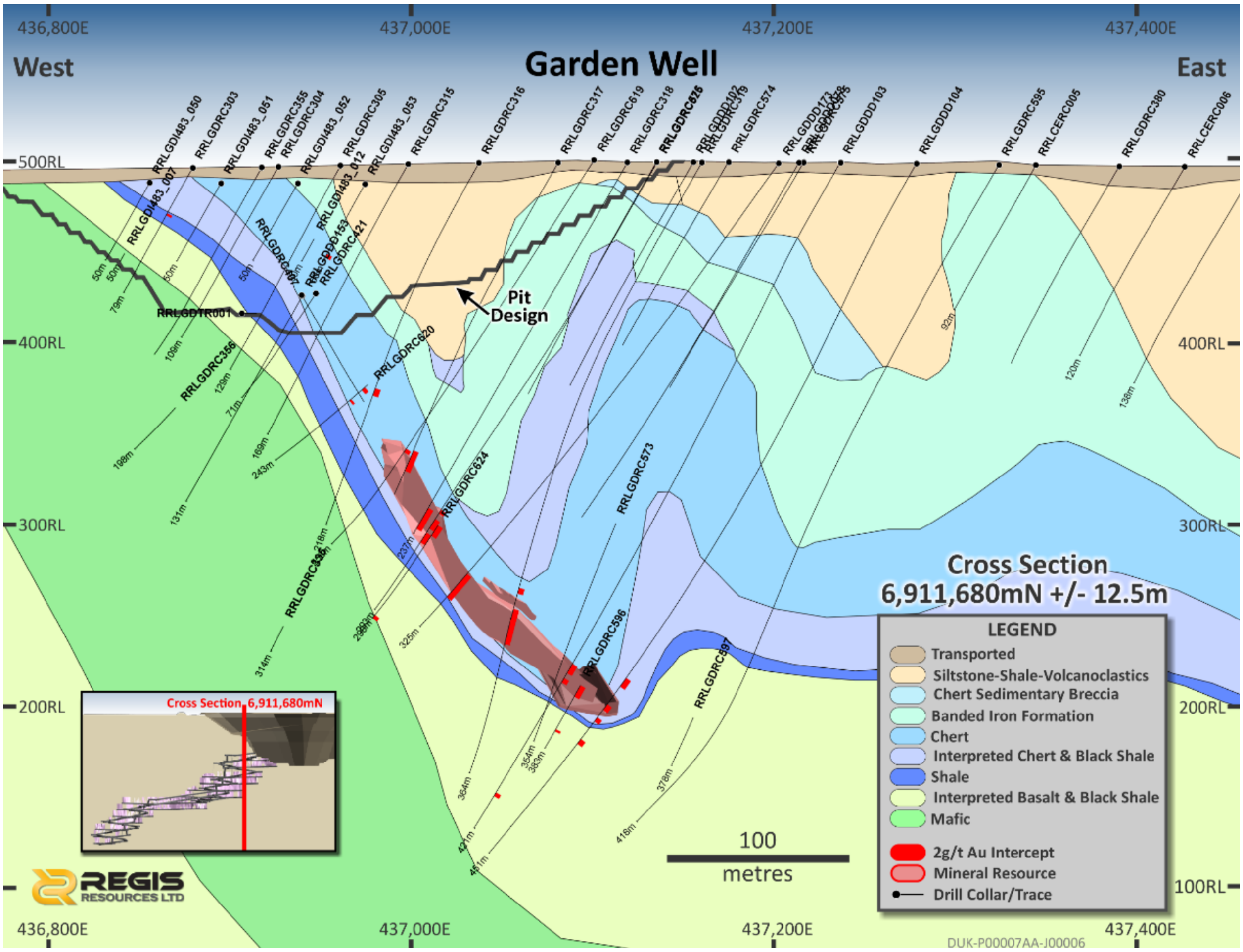



**Figure 1 Geological cross-section looking north through the Garden Well South mine**

# 3 Vuggy and cavernous conditions

Naturally occurring voids (also called vuggs, vughs or vugs) created through natural geological processes are being frequently encountered during development of the GWS underground mine. A vugg is a small- to medium-sized cavity inside rock. It may be formed through a variety of processes. Most commonly, cracks and fissures opened by tectonic activity (folding and faulting) are partially filled by quartz, calcite and other secondary minerals. Open spaces within ancient collapse breccias are another important source of vuggs.

In the case of GWS, vuggs have been specifically formed within the black shale and chert-shale unit, which sits on the immediate footwall (and in some cases overlaps mineralised zones) of the GWS orebody. Locally this has been termed as the ‘transitional zone’. Vuggs have been observed to be tens of centimetres and up to about 20 m in length to date (see Figures 2, 3 and 4). This is a high permeability zone with associated natural vuggs and cavities lined with recrystallised euhedral quartz crystals. The vuggy zone was firstly identified through exploration core logging of diamond drill holes, in the form of core loss and veining showing vuggy quartz crystals aligned to the metasedimentary layering.

Vuggs have been frequently encountered and successfully managed throughout the mining of the Garden Well open pit. Underground mining has presented additional challenges for the identification and mitigation of such vuggs.

**Figure 2 Vugginess evident at the scale of drillcore**

**Figure 3 Vugginess evident at the scale of a tray of drillcore**


**Figure 4 Large-scale cavity at the scale of an underground development drive**

The zone has been identified plunging at the same orientation as the local folds hinge and is mainly contained within the chert/shale unit. The axial plane to the folds is north-northwest–south-southeast striking and steeply east-northeast dipping. The natural cavities seem forming an overall tube-like geometry that plunges down to the south-southeast, along with the local fold hinges, and the geometric controls upon the vuggs spatial distribution are consistent between underground observations and diamond drill cores. The vuggs host rocks ranging from poor (shale dominant rock mass) to good–very good ground (chert dominant).

# 4 Geotechnical setting

There are five main geotechnical domains at GWS underground gold mine based on rock type, deformation and associated structures comprising, from west to east, footwall mafic shale, footwall shale, high permeability/void zone, BIF/chert hosted orebody and hanging wall sedimentary rocks. Table 1 summarises the expected rock mass conditions for each domain or rock type.

**Table 1 Typical rock mass quality for Garden Well South underground domains**

| Geotechnical domain | Typical rock mass quality rating |
|---|---|
| Footwall mafic shale BVS | Fair–very good |
| Footwall shale | Very poor–fair |
| High permeability/void zone | Very poor–fair |
| BIF/chert hosted orebody | Good–extremely good |
| Hanging wall sedimentary rocks | Good–very good |

The mining method used at GWS is a combination of open stoping with pillars in narrow areas, open stoping with loose rockfill in selected areas, and longhole open stoping with cemented rockfill in large bulk mining areas utilising a primary-secondary mining sequence.

## 4.1 Structural model

Significant effort was undertaken to understand the structural and geological controls leading to the occurrence of the vuggy ground conditions. This was initially undertaken by Regis Resources, and further supplemented by way of engagement of a specialist structural geologist. The structural geologist spent significant time reviewing drillcore and undertaking mapping within the existing open pit and underground to understand the structural controls. This work resulted in a deeper understanding of the controls and, therefore, the likelihood of occurrences of voids or vuggs in future mining areas.

# 5 Ground support

The following section describes ground support practices and their development at GWS underground gold mine.

## 5.1 Ground support practices

In general, the rock mass at GWS is defined by 'typical ground' which, for ground support purposes, is separated by excavation design dimensions and geological units/domains, and then 'vuggy ground' (transitional zone) which is designated using the 3D vuggy zone model as rock mass with a likelihood of encountering natural vuggs.

Within the typical ground, ground support is generally 47 mm 2.4 m split sets, 5.6 mm weld mine mesh, or 47 mm 2.4 m split sets and 50–75 mm of 32 MPa fibrecrete, depending on the assigned ground support standard design, which is designated at the level plan design stage. The mine is shallow so there are no stress-related issues and water is mildly salty so corrosion is not a major issue at present, although it will play a part in some sections of capital development as the mine life is extended. A corrosion-monitoring program is currently in place to establish corrosion rates underground and to map the mine to identify areas where higher corrosion rates are expected and need to be monitored to eventual re-supporting, depending on access requirements.

The transitional zone is shown on all development designs and mining instructions. This boundary defines where development goes away from the standard ground support designs used in typical ground and support is determined using the ground support trigger action response plan (TARP) and the special ground support standard (Figure 5). In general, the ground within the vuggy zones around the physical vuggs is competent, so issues with unravelling or significant overbreak are rare. As the understanding of how the rock mass in these zones performs during development has increased, the ground support design has evolved to the current version of the TARP (Figure 6):

- For all TARP levels (apart from Level 1c), 50 mm of fibrecrete is sprayed onto the unsupported heading floor to floor. This acts to provide initial surface support and can be sprayed into any vuggs that are present to support the surfaces within them.
- 2.4 m 47 mm split sets and mesh are installed over the fibrecrete.
- If the ground is assessed as Level 2, another 25 mm of fibrecrete may be applied over the top of the bolts and mesh to stiffen up the support. Spiling for the next cut is installed by way of 3.0 m split sets installed in the backs and shoulders for the next cut at an angle of +10° from the horizontal. Although this is not traditional practice for spiling and would not be as effective in a weak rock mass, it is a quick and simple solution that helps hold the vuggy ground to profile while the next cut is fibrecreted and rockbolts installed.

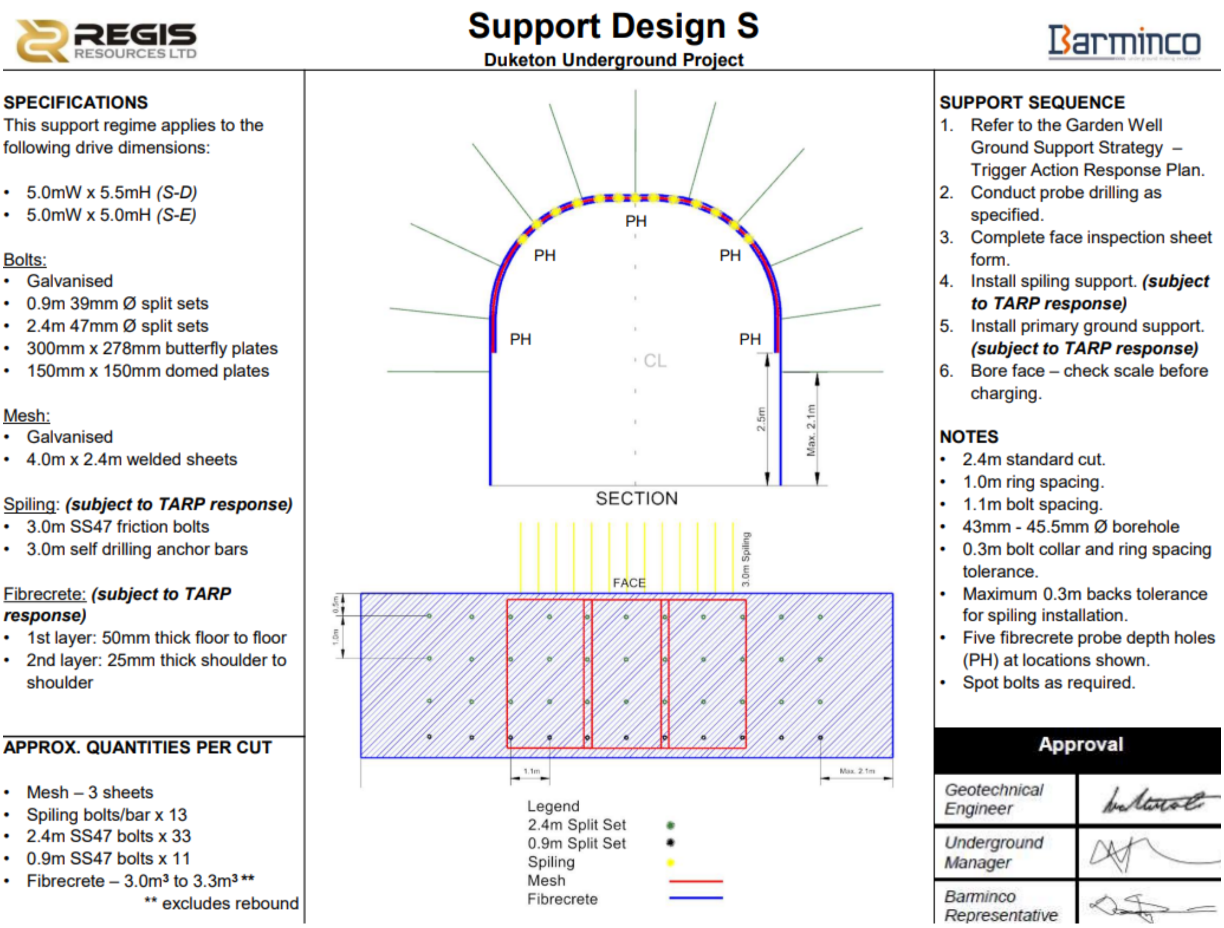



**Figure 5 Ground support standard used in vuggy rock mass conditions at Garden Well South underground mine**

| GDW Ground Support Strategy TARP – Version 08 | | | Effective Date: 11 February 2023 |
|---|---|---|---|
| | **Level 1 Triggers** | **Level 2 Triggers** | **Level 3 Triggers** |
| **Visual Observations** | Competent ground conditions.<br>No significant structures.<br>Dry ground. | Poor or blocky ground conditions.<br>Minor structures.<br>Mostly dry ground. | Poor or blocky ground conditions.<br>Excessive overbreak in heading.<br>Wet ground. |
| **Probe Drilling** | No vuggs or small vuggs (≤ 0.5 m wide) encountered. | Small vuggs encountered (0.5 to 1 m wide) in backs or floor. | Large vuggs encountered in backs or floor (>1 m wide). |
| **Geological Model** | Good ground & no/minimal vuggs modelled in the next 5 m. | Fair - Poor ground and/or minor vuggs modelled in the next 5 m. | Poor ground and the potential for large vuggs modelled in the next 5 m. |

| | **Level 1 Response** | **Level 2 Response** | **Level 3 Response** |
|---|---|---|---|
| **Ground Support Strategy** | If profile is poor/overbroken:<br>**Response 1a**<br>No spiling bars.<br>Continue with perimeter control measures.<br>1 x short round - 2.4 m.<br>50 mm layer of FRS floor to floor.<br>Split sets and mesh GSS as per drive dimension on MI.<br><br>If profile is maintained in Poor to Average ground:<br>**Response 1b**<br>1 x Full length round (≤ 3.5 m).<br>50 mm layer of FRS to gradeline.<br>Split Sets and Mesh GSS as per drive dimension on MI.<br>No second layer of FRS.<br><br>If profile is maintained in previous cut supported with 1b, and ground appears Average to Good:<br>**Response 1c**<br>Full length round (≤ 4.0 m).<br>Split sets and mesh GSS as per drive dimension on MI | Install un-grouted 3.0 m split sets as spiling bars.<br>Continue with perimeter blasting control measures.<br>Short round - 2.4 m.<br>Initial 50 mm layer of FRS.<br>Split sets and mesh GSS as per drive dimension on MI.<br>No 2nd layer of FRS in ore-drive.<br><br>**If deemed necessary by Shiftboss/Foreman or Geotech:**<br>Second layer of 25 mm FRS.<br>Lag 2nd layer of FRS by ≤ 8 rounds.<br>(2nd layer of FRS only applicable in cross-cut).<br><br>**Foreman / Shift Boss are required to make the decision to move from Level 1 ↔ Level 2.** | Geotechnical inspection and review is required to establish an individual ground support strategy and plan of implementation. An Additional Ground Support memo will be designed and released.<br><br>**UGM / Alternate UGM is required to make the decision based on Geotechnical input, to move from Level 2 ↔ Level 3.** |

- Every cut is to be probe drilled with a minimum of 2 holes in the face and 3 holes in the floor – location of holes is shown in the MI GSS. Location of holes can be adjusted by the operator based on the geology of the current face (target areas most likely to contain vuggs). In addition, **drill 5 vertical holes in the floor 1m back from the face.**
- Probe holes to be drilled using 4.9 m steel (~ 4.1 m probe hole).
- Report hole location and comments to Shift Boss / Regis using the Face Inspection Sheet for TARP response.
- Response can only be downgraded from current bin with approval from appointed personnel (Shift Supervisor, UGM, Alternate UGM, Geotech).

**Figure 6 TARP used for developing through vuggy ground conditions at Garden Well South underground mine**

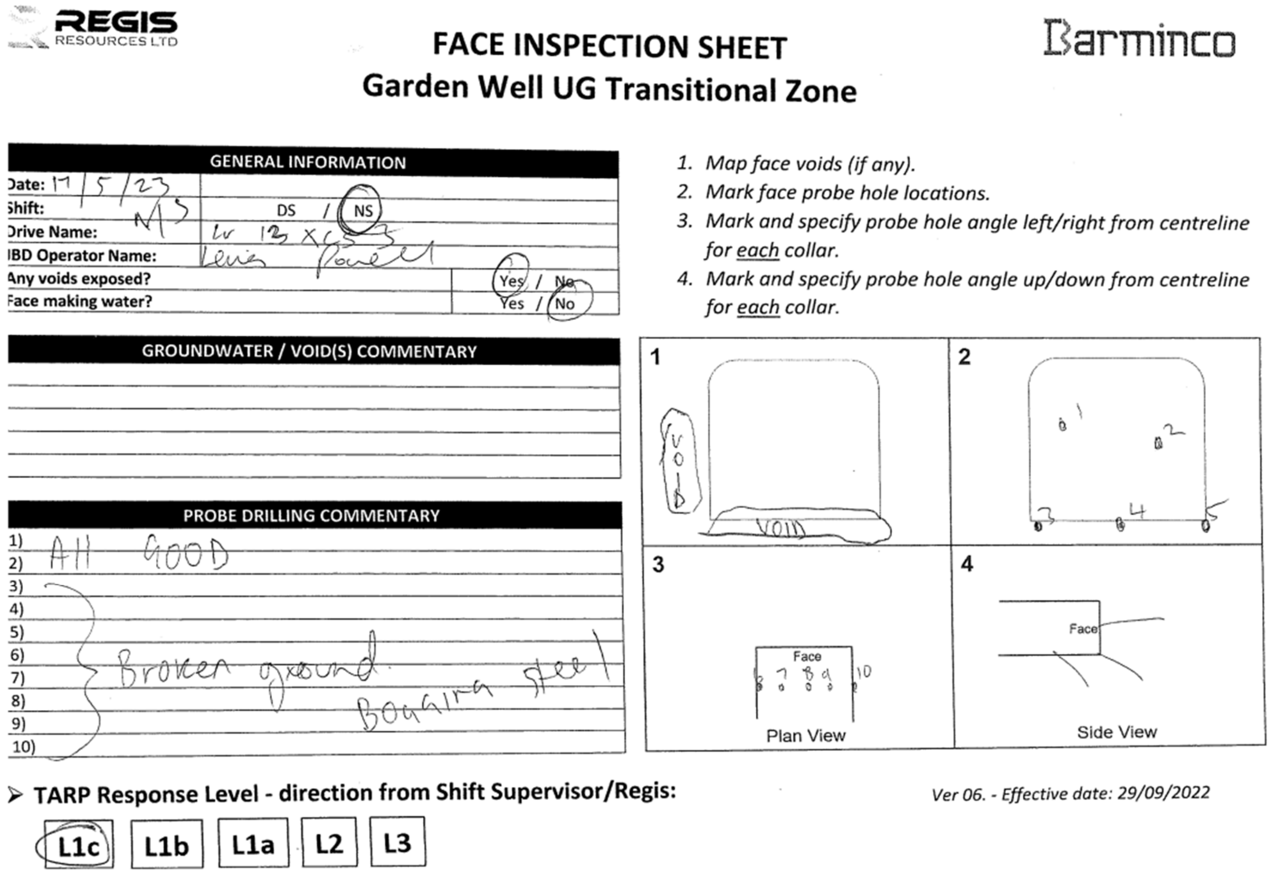
Using the TARP and special support standard to dictate support requirements for each cut has worked well to date and the different combinations of fibrecrete, split sets and mesh are appropriate for the majority of the ground encountered in the transitional zone. Additional support in the form of cable bolts (typically 6 or 9 m in length) is sometimes installed following geotechnical assessment and review. This is usually undertaken where larger voids form 'brows' within the development, or where probe drilling has identified broken ground or voids in the backs.

Only a small number of vuggs encountered have resulted in a bypass drive or alternative development designs being devised. For one of the large voids encountered within oredrive development, filling with a foaming-type resin was investigated to allow development to continue safely. Although the products are available and would have likely performed well, the cost of this and time delay involved in mobilising offsite contractors to undertake the work was ultimately the deciding factor in not trialling this method and instead changing the development sequence and drill and blast design. It was however a useful exercise to now have the contacts and key information for informing decision-making on any future large voids that may have a greater impact on stope extraction if they are not filled.

Voids discovered in the floor following probe drilling that are perceived as having the potential to subside/break into the drive are either fired using the jumbo to drill blastholes, or a larger hole is reamed out and low-strength grout poured into the vugg using an agitator truck. This has been undertaken on only a handful of occasions but has been successful. The void volume is carefully reviewed and estimated from probe drilling and surveying, and quantities of placed cemented fill are carefully recorded to ensure completeness of filling has occurred.

## 5.2 Development practices

Probe drilling utilising the jumbo and 4.9 m drill steels forms a critical part of the development cycle when in the transition zone (vuggy ground). All probe results are plodded by the jumbo operator (Figure 7) and reported to Regis by the project engineer or foreman via email each morning (for the past 24 hours). Conditions encountered within the probe drilling determine the level of response required (based on the TARP) for the proceeding development round. Refer to the TARP for how this is assessed and escalation of response levels depending on probe results.



REGIS RESOURCES LTD

**FACE INSPECTION SHEET**
**Garden Well UG Transitional Zone**

Barminco

**GENERAL INFORMATION**

Date: 17/5/23
Shift: DS / NS
Drive Name:
IBD Operator Name:
Any voids exposed? Yes / No
Face making water? Yes / No

1. *Map face voids (if any).*
2. *Mark face probe hole locations.*
3. *Mark and specify probe hole angle left/right from centreline for each collar.*
4. *Mark and specify probe hole angle up/down from centreline for each collar.*

**GROUNDWATER / VOID(S) COMMENTARY**

**PROBE DRILLING COMMENTARY**

1)
2) All good
3)
4)
5)
6)
7) Broken ground
8)
9)
10)

1 2 3 4
Face
Plan View
Face
Side View

➢ **TARP Response Level - direction from Shift Supervisor/Regis:**

*Ver 06. - Effective date: 29/09/2022*

**L1c** **L1b** **L1a** **L2** **L3**

**Figure 7 Example of a probe drilling record sheet used during development within the transitional zone at Garden Well South underground mine**

# 6 Vugg and void management plan

A vugg and void management plan was drafted in August 2022 (Parrott 2022) to provide a framework of the formal processes for the consideration of voids: managing interactions with voids and cavities; outlining the actions, timing, and roles and responsibilities for dealing with voids and vuggs; void monitoring strategies; assessment of inherent risks; creating workforce instructions; and identification of activities related to the mining. The formal structure of the initial document was:

1. Technical considerations of the mine including a geological and geotechnical conditions overview.
2. Inherent risks:
    a. Mining activities interacting with vugg/void.
3. Void identification, monitoring and mitigation of risks:
    a. Void identification and management.
    b. Identification of the presence of voids through either diamond drilling or probe drilling.

c. Impact of voids on development stability and worker safety, and void stand-off distances.

d. Appropriate development practices.

e. Avoidance through redesign or cessation of mining practices.

f. Monitoring.

g. Modelling including guidelines for development and maintenance of a three-dimensional void model.

4. TARP overview and current version.

5. Roles and responsibilities for all relevant personnel.

As part of the management of vuggs and voids underground, a TARP was developed to manage all vugg interactions as they occur on a daily basis when encountering new or existing voids at GWS underground mine. This TARP has been the key aspect to the day-to-day interaction and management of the vuggs. It has given the mining contractor the confidence to make decisions based on their learned experience and discussions with the geotechnical team as development has progressed. Building this confidence and working with the operational team are critical parts of having development within non-standard areas succeed, and allow mining rates and priority headings to progress in line with the mining schedule.

One of the most important aspects of both the Management Plan and the TARP is the regular review and updating based on the experiences and learnings underground. The workforce was encouraged to think about this, and many discussions were had on what was working well and what could be altered to improve the process and keep development headings on schedule. The TARP is now at Version 8 and is fully integrated into the daily mining operations, with the mining contractor allowing development rates to continue in line with mining schedules even when vuggs are present. All documents fall under the Ground Control Management Plan (Montaldi 2023).

# 7 Concluding remarks

The GWS underground mine encountered vuggy and cavernous rock mass conditions which required adaptation of ground support practices to ensure the safe and efficient construction of tunnels. To aid in this development, rigorous ground support standards were implemented and a vugg void management plan was devised and adopted. A key aspect of development within vuggy rock mass conditions has been communications with underground development crews, and the implementation of a TARP to manage and mitigate issues tactically, at the face, as development is occurring. Operators have the training, knowledge and framework for decision-making to effectively respond to conditions as they present themselves.

# Acknowledgement

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# References

Montaldi, L 2023, *Regis Resources Garden Well South Ground Control Management Plan*, internal document,
Parrott, T 2022, *Regis Resources Garden Well South Vugg Void Management Plan*, internal document.