

# Exploration and Innovation □ The Discovery and Evolution of the 2 Moz Vogue Gold Resource, Sunrise Dam Gold Mine, Western Australia

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## ABSTRACT

The 2 Moz Vogue mineral resource is a recent discovery at the Sunrise Dam gold mine (SDGM), lying approximately 600 m vertically below the Sunrise Dam open pit. Unlike most other lodes, which are dominated either by steep vein sets or shallow high-strain (shear) zones, it lies broadly in the hinge of a folded felsic porphyry body, where it cuts intermediate volcanic lavas and volcanoclastic rocks and is not specifically concentrated at a lithofacies contact. The mineralisation is controlled by a complex interplay of moderate to shallow, west-dipping high-strain zones that are transected by irregular and discontinuous high-grade, north-west-, north-south- and east-west-trending breccia sheets that initially caused problems with attempts to model broad domains. However, by combining the structural controls and styles with the distribution of gold, arsenic, sulfur and antimony, we have improved opportunities for scheduling, extracting and processing the most appropriate material considering the current mining and processing constraints.

The early delineation process for the Vogue lode revealed a significant mineral resource for the SDGM, coupled with the recognition of some potentially difficult downstream implications for mining and processing. The ultimate success of mining at Vogue will be a consequence of combining standardised data collection and geological modelling techniques with the results of the novel innovative techniques applied at an early stage of the project.

Innovation (in the truest sense) drives change and application to deliver efficient and effective outcomes. Initial data generation and interpretation in lodes above Vogue provided a sound geological model based on strong structural foundations, leading to ideas that could be tested and validated by stress inversion analysis and modelling simulations. Geomechanical modelling simulations, based on the structural analysis, then provided an insight into both the structural and fluid evolution of the system and highlighted target areas. This promoted support for deeper drilling and sampling, which led to the discovery of Vogue.

With additional data, the structural model for Vogue was re-engineered through combination with geochemical and hyperspectral analysis and detailed geological and geostatistical domaining. Initial poor results from metallurgical tests from a small batch sample refocused efforts to undertake mineral and chemical characterisation and profiling (geometallurgy) and combine this data with the composite geological-structural-geochemical model. The result is a conditional probability model for differentiating mineralised or waste domains, with direct outcomes for planning, drilling and mining.

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## INTRODUCTION

The 15 Moz Sunrise Dam gold mine (SDGM) is located approximately 850 km east-north-east of Perth and 45 km south-south-east of the township of Laverton in the central Laverton Tectonic Zone of the Eastern Goldfields Province, Western Australia (Figure 1). Sunrise Dam is the single largest gold deposit in the Laverton Tectonic Zone. From the 16 year production history, approximately 9.5 Moz have been produced, with approximately 7.5 Moz produced from the open pit and 2 Moz produced from underground operations. The open pit operations ceased in February 2014, and the underground mine has now become the primary source of ore. It is forecast to produce 2.4 Mt of ore in 2014 and is projected to maintain or even exceed this level of production over the next five years. Mineral Resources and Ore Reserves as of 31 December 2013 are: 44.8 Mt at 2.24 g/t Au (3.23 Moz Au) and 21.1 Mt at 1.73 g/t Au (1.18 Moz Au) respectively.

The most significant discovery in the Laverton region and at Sunrise Dam in the last ten years is the >2 Moz Vogue mineralisation in 2012, in combination with the 2013 discovery of the higher-grade Sunrise Shear Extensions and Cosmo East Mineral Resources. These discoveries have added approximately 275 000 oz in Mineral Resources and 120 000 oz in Ore Reserves to date through specific geological and scientific applications, coupled with strategic and systematic targeting and planning by the Exploration Department.

This paper provides a geological overview of the newly discovered Vogue mineralisation and discusses the interrelationship between conventional data collection and innovation using the Vogue mineral resource as an example. Furthermore, it draws on the collaborative and cumulative learnings from staged sampling and re-evaluation of geological and statistical models to understand the characteristics of the mineral resource and highlight, in advance, the potential implications for mining and processing.

## SUNRISE DAM GOLD MINE GEOLOGY

The detailed geology of the Sunrise Dam deposit has been described by Nugus, et al 2013, Nugus and Biggam (2008), Blenkinsop et al (2007), Baker et al (2010) and Sung et al (2009). It can be summarily described as a structurally complex series of gold-rich domains with a variety of ductile and brittle deformation fabrics that influence the nature, geometry and distribution of the gold mineralisation.

The Sunrise Dam stratigraphy consists of a complexly deformed and altered package of shallowly north-west-dipping units that are dominated by intermediate volcanoclastic rocks, lavas and intrusives (Figures 2 and 3). These have been unconformably overlain by a sequence of generally well-sorted siltstones, sandstones and magnetite-hematite-rich siltstones, sandstones and shales, which consistently fine upwards. These sediments and volcanic units have been intruded by dolerite sills, which invert the sequence by up to 100 per cent and are most evident in the northern end of the deposit. Minor units include quartz diorite sills and ultramafic rocks. Felsic porphyry dykes that cross-cut the stratigraphy are evident within most parts of the deposit. The type example 'Dolly Porphyry' was dated by Brown et al (2002) as  $2654 \pm 8$  Ma in age (U-Pb SHRIMP zircon) and are rhyodacitic in composition, with albite, K-feldspar, varying quantities of quartz, and sparse ferromagnesian minerals in least-altered varieties. Although termed 'porphyries', the porphyritic texture is commonly absent or poorly developed, with an equigranular crystalline texture that is generally unfoliated and unaltered away from the margins. Late-stage lamprophyre dykes are Palaeo-Proterozoic in age ( $2080 \pm 4$  Ma) and cross-cut the stratigraphy and foliations within the deposit. Transported, fluvial-lacustrine and aeolian sediments cover the deposit (Nugus et al, 2013).

Gold mineralisation is extensive and complex at the mine-scale. However, it can be rationalised into three distinct categories based on the nature, geochemistry and timing of the host structure. These are:

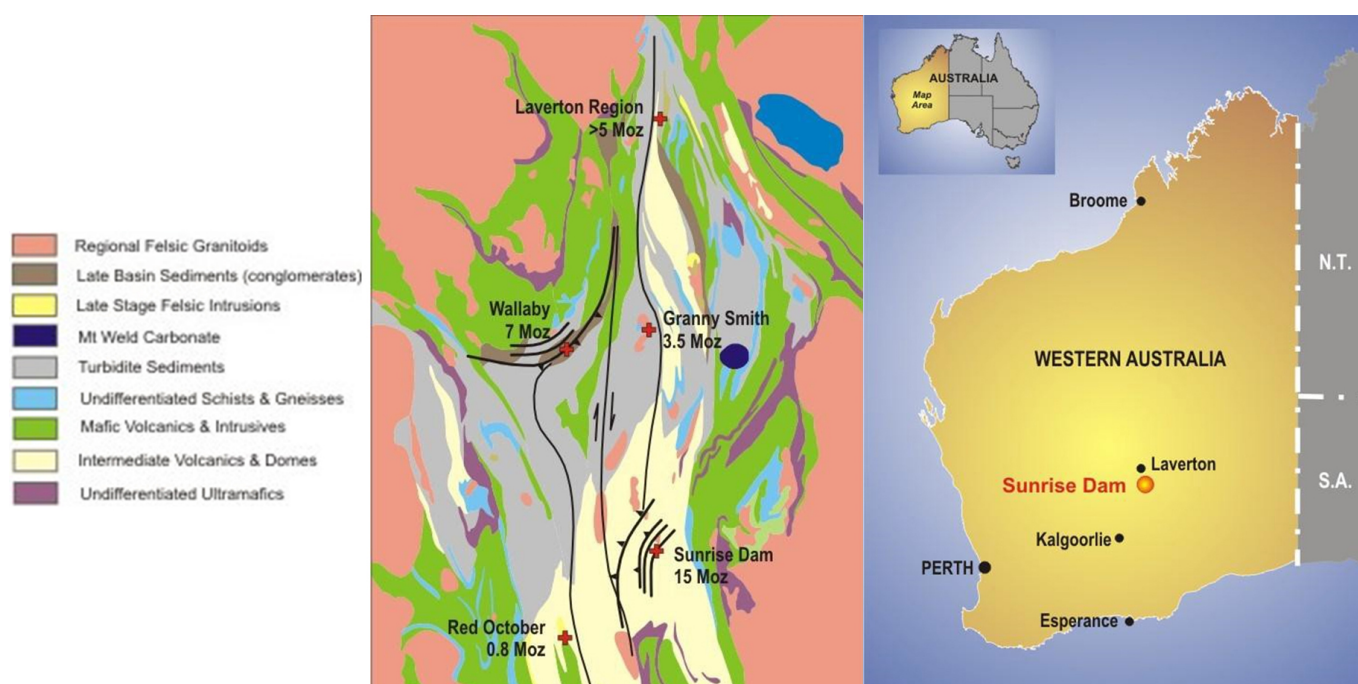


FIG1 – The location of Sunrise Dam gold mine and the generalised geology of the central Laverton Greenstone Belt, Western Australia. The deposit is symmetrically opposed to the generalised architecture hosting the Wallaby gold deposit, and Sunrise Dam is located in a uniquely anomalous domain that is dominated by west-dipping stratigraphy and structures. Sunrise Dam is the largest individual gold deposit in the belt.

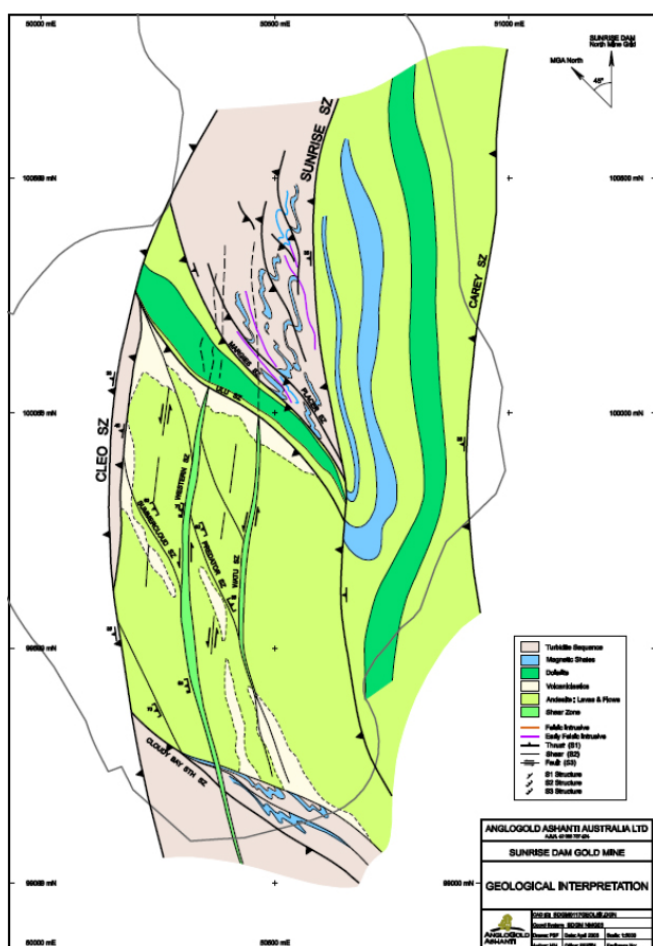


FIG2 – Plan view of simplified geology projected to the 2100BRL illustrating north-west and north-south trending primary shears (thrusts) and later stage faults. Additional complexities and folding occurs within the upper metasediments.

1. Orthogonal breccia zones – extensional veins in distinctive steep and flat dipping fault zones that generally have narrow (<1 m) alteration zones and coarse gold, pyrite and commonly arsenian pyrite and characteristic breccia textures (Figure 4). Within these consistently high-grade lodes, some gold is intergrown with tellurides and silver (Sung et al, 2009). McLellan et al (2007) and Baker et al (2010) agree that these lodes are preferentially developed through hydraulic fracturing as a consequence of over pressurisation and subsequent phase separation processes, which supported the coincident generation of steep fault and breccia zones that form as sheets or oblate pipes.
2. Shear controlled – these may occur as extensive schist development with specific shear veins with extensive alteration halos and localised extensional veins with zoned quartz-carbonate-pyrite veins with gold mineralisation. The shear veins generally contain grades between 0.5 and 3 g/t Au. The Sunrise Shear Zone is an example of this type of mineralisation.
3. (Lower strain) stockwork domains – which are discrete and well delineated zones where original shears have been extended, veined and brecciated by subsequent alteration and veining episodes, resulting in fracture and breccia domains. These have very complex internal geometries, and mineralisation is variable continuous and poorly understood by most. The strain is not as discretely focused as within the shear zones and it is distributed throughout a broader zone, which is manifested as local high-strain,

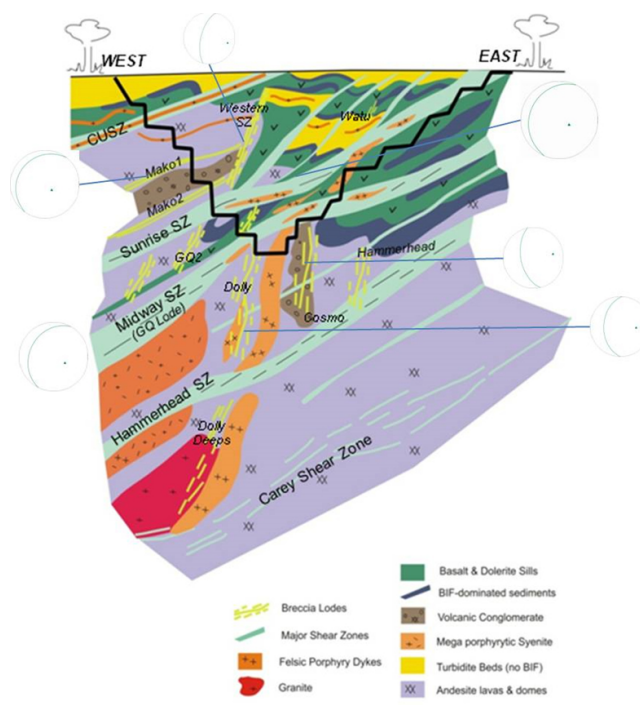


FIG3 – A composite cross-section through the mine (adapted from Nugus and Eggam, 2008). The geometry of shallow-dipping shears and steeply dipping breccia domains is consistent throughout the mine area. The upper turbidites clearly overlie the basement volcanic and volcanoclastic rocks, which are all in turn deformed and cross-cut by felsic dykes. The subsequent breccia-filled faults create a complex interplay between gold mineralisation, structure and lithological contacts. The Dolly Deeps (renamed as Vogue) is the new discovery at Sunrise Dam.

schistose/shear bands and subsequent, overprinting stockworks. They contain a significant amount of high-grade gold in fractures and shears that may locally exceed 100 g/t. However, the volume of low-grade and waste material that is intercalated with the stockwork domain reduces the overall gold grade of the mineral resource to approximately 3.5 g/t Au. The most notable domain is the Midway Shear Zone (MWS or GQ Lode).

Shear veins are identifiable as laminated black and white crack-seal and pressure solution veins (Figure 4; top) that are associated with periodic slip and possible seismicity. These veins are commonly very high grade, with visible gold, and they commonly contain base metal sulfides (Cleverley et al, 2007; Sung et al, 2009; Nugus et al, 2005a). This differentiation is made more complex when overlapping ore zones develop into complex stockworks where the shear-hosted mineralisation is extended, inflated and hydraulically brecciated with subsequent discontinuous mineralisation of several stages. Detailed paragenetic alteration and veining studies (Hantler, 2010) have proven complex and ambiguous, which supports the reactivation and cyclicity of the Sunrise Dam mineralisation system (Nugus et al, 2005; Baker et al, 2010).

This is the nature of mineralisation within the GQ lodes and at the footwall and southern areas of the Sunrise Shear Zone. The average gold grades for mineral resources in these areas are 3.5 g/t Au and they can form in excess of 5 Mt of material.

### VOGUE DISCOVERY

A thorough understanding of the structural controls of the continuity, orientation and geometrical constraints of this

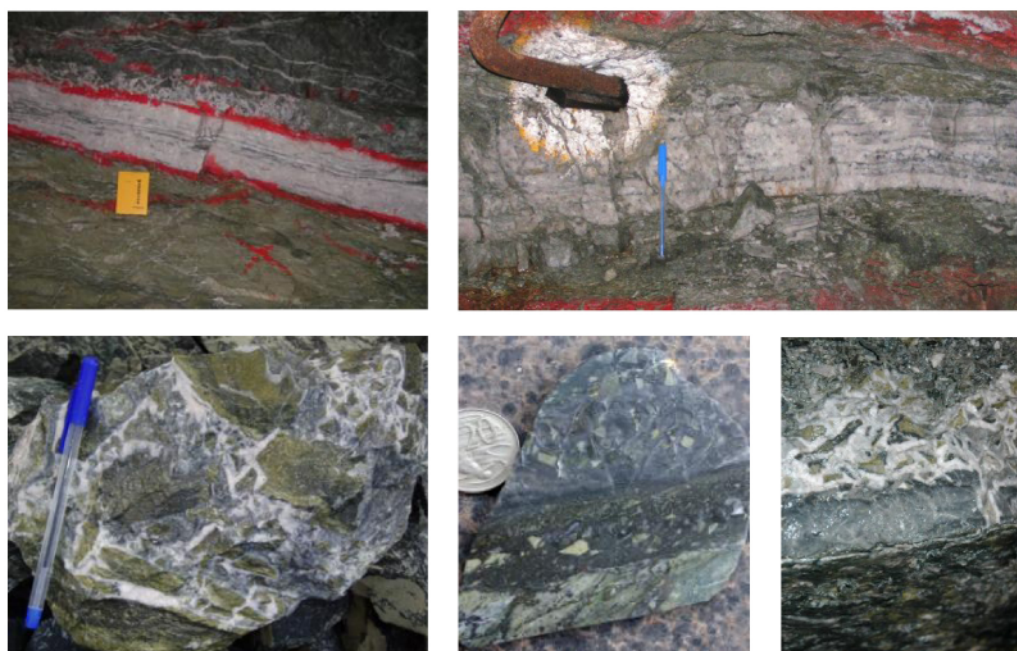


FIG 4—Collage of mineralisation styles within Sunrise Dam. The nature of shear zones with overprinting breccia and shear veins reinforces the cyclical and reactivation of structures to enrich the deposit. (top) – Sunrise Shear and Midway Shear. (bottom) – high-grade and fault-related, Western Shear, Cosmo, Wetalode breccias

mineralisation was deemed critical to be able to implement and design effective exploration and drilling campaigns. Success from the exploration work and resultant mineral resource models would be the cornerstone on which mine design, planning and scheduling would be built, especially in the early stages of the underground mine. The details of the structural model were gleaned from available open pit and underground exposure with diamond drill core measurements. The structural characteristics of the Sunrise Dam deposit have been described previously (Newton et al, 1998; Tornatora, 2002; Davis and Maidens, 2003; Miller and Nugus, 2006; Blenkinsop et al, 2007). A deformation and mineralisation history is included in Table 1.

At Sunrise Dam, the initial underground exploration strategies and associated budgets were built on detailed structural and mineralisation models that established a consistent architecture and structural framework. An

understanding of the kinematic controls at a regional, deposit, lode and stope scale was an important component of this work (Figure 5). The immediate implications of this revealed that the gold mineralisation and structural history were intimately linked with a fluid pressure-induced fracture array developed on a pre-existing and mineralised thrust and shear system. The fractures and associated mineralisation were preferentially concentrated in a ‘Riedel-like’ pattern that intersected existing cleavages and shears and at lithofacies contacts, especially volcanic conglomerates and andesite lavas, or juxtaposing the felsic porphyry dykes (Nugus et al, 2005).

From this structural and mineralisation model, analogous positions at depth were interpreted and it was predicted that additional mineralisation would occur at depth and to the south-east of the Dolly Lodes as discrete domains in the Midway Shear and to the south-east of the Cosmo mineralisation (Figure 5).

TABLE 1  
Structural and mineralisation history at Sunrise Dam Gold Mine

Event	Kinematics	Shortening	Vein styles	Mineralisation
Extension	E-Westension 21 Ga		Lamprophyre dykes	Umineralised
D6?	Dextral conjugate faulting	E-W?	Qtz-carb+qtz	Umineralised
D5	Sinistral faulting	ESE	Qtz-qtz-carb-coarse pyr	Umineralised
D4b	Dextral faulting (late stage) reactivation and extension	NE	Qtz-carb-drl-pyr-base metals and tellurides-drl-cg pyrite-qtz-carb	Localised high-grade in Qtz
D4a	Dextral faulting (early stage)	NE	Qtz-carb-asp-pyr-ser-tellurides(?)	Major mineralisation
Porphyry	Dyke intrusion 2674 ± 3 Ma Gannu Smith porphyry 2677 ± 6 Ma	NNE?	Qtz-alb-hmt-pyr	Umineralised
D3	Thrusting and sinistral shearing	SE	Qtz-carb-ser-pyr+drl-asp-qtz-carb-alb-py	Moderate grade mineralisation throughout Sunrise Shear Zone
Porphyry			Qtz-alb	Umineralised
D2?	Regional E-W shortening	~E-W	Carb-qtz-drl	Umineralised
D1	NW thrusting? NW extension?	NNW? NE?	Siliceous, fragmental veins with grey (drl?) sulfide poor matrix	Au (0.25–1.5 g/t Au), no As or base metals

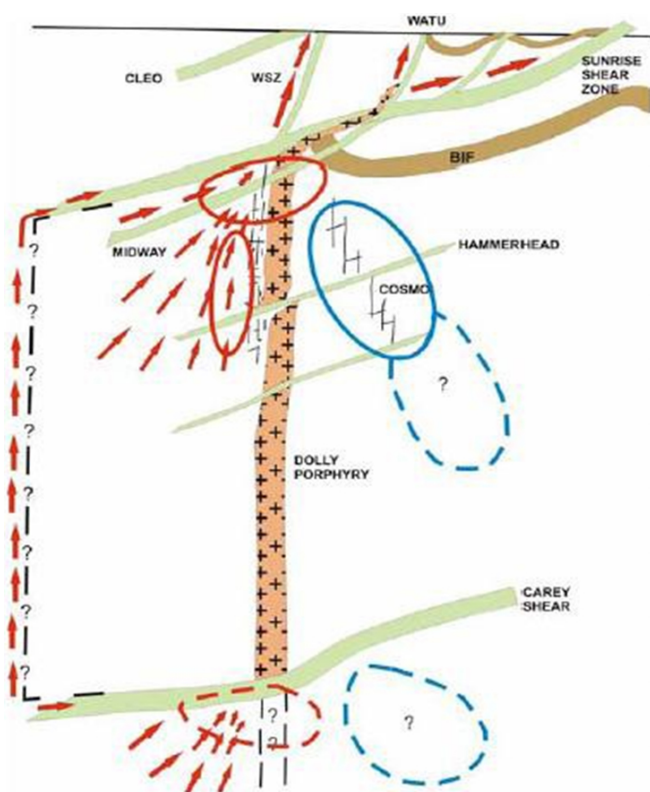


FIG5 – Schematic and ultra-simplified diagram of proposed model and target positions from structural, drill hole and geological analyses and interpretations, coupled with 3D numerical models and fluid flow and deformation simulations (Benkinsop et al, 2007). The target positions lie to the west of the felsic porphyry, in areas to the south-west towards the Carey Shear Zone and to the east-south-east of the Cosmo lode. The Vogue domains and extensions to the Carey Shear and Cosmo East lodes have all been subsequently discovered by the Exploration Department.

It was immediately recognised that even though the targets were valid and well-supported, the physical testing of the exploration targets required long drill holes. But the extensive amounts of capital development that would be required would need a commitment of between \$5 M and \$10 M in the next year. Drill testing of the extensive target area at 80 × 80 m to 80 × 160 m would require a minimum of \$20 M without a more focused target.

It was recognised that drilling and development of the postulated deeper targets to a mineral resource level would cost in excess of \$60 M over three to five years. Therefore, a technique to validate the structural analysis was sought, and development of geomechanical modelling options was specifically undertaken.

Geomechanical modelling has been proven as a useful tool in simulating coupled deformation and fluid flow processes and targeting mineralisation (eg McLellan et al, 2004; Schaubs et al, 2006; McLellan et al, 2014a, 2014b). The main aims of this work at Sunrise Dam were three-fold:

1. to ascertain the distinct structural events and primary stress vectors that led to mineralisation by conducting a 3D stress analysis for inputs into numerical models
2. to simulate both major deformation events (D3 and D4) associated with gold mineralisation to identify areas of failure, increased shear strain, dilation and fluid focusing
3. to validate the target locations and the mechanical modelling results themselves prior to any proposal for a financial commitment by the operation.

Conceptual geomechanical models were developed, based on the SDGM structural database, and converted into a hexahedral mesh, and then deformed in accordance with the stress analysis results and the deformational history.

Kinematic analyses of models were undertaken with varied pore pressure regimes, which allowed us to test failure distribution under different proposed conditions. During D3 ( $\sigma_1$  at 135°), maximum values of shear strain are focused on the shear zones. When pore pressures are increased towards lithostatic values, dilation is focused in three particular locations above and below the Sunrise Shear Zone (SSZ) and around the deep shallow-dipping shear zones (analogous to the MWS and Carey Shear Zones) and Dolly Porphyry intersection (Figure 6A), which may be most likely influenced by the intersections of the shear zones. Due to a lowering of permeability of the SSZ (acting as a seal) during D4 deformation ( $\sigma_1$  at 038°), we see a focus of tensile failure around the south-west corner of the Dolly Porphyry (Figure 6B). The distribution of maximum dilation around the south-west intersection of the felsic porphyry (Dolly Porphyry) and the shallow-dipping shears at depth is clearly evident during D4 deformation (Figure 7). This orientation and plunge of the maximum dilation values was one of the key criteria in defining a deep drilling target.

Following this work, and due to limited drilling platforms in the southern end of the mine, three specifically sited diamond drill holes were drilled down the projected plunge of the key target within what is now known as Vogue. When development positions allowed, extended holes were drilled to the east of Cosmo, which intersected high-grade

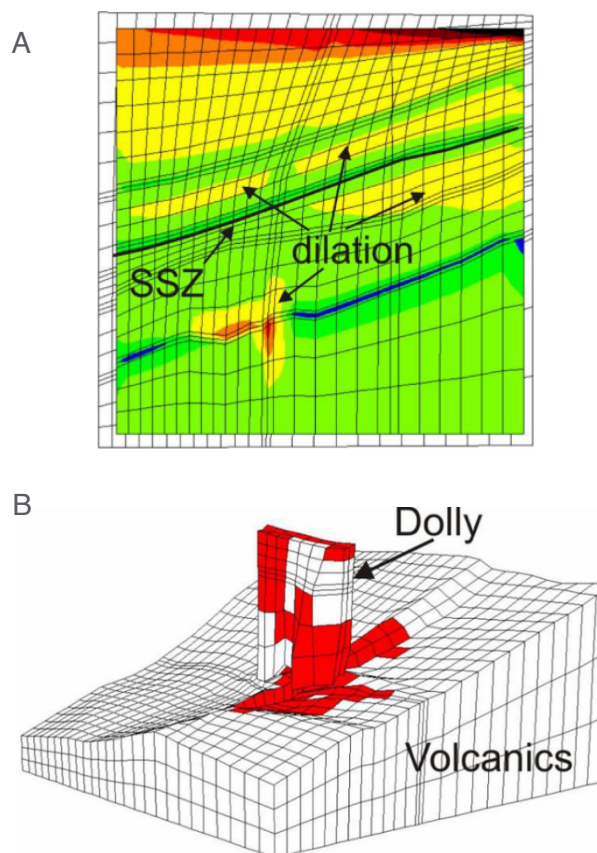


FIG6 – Distribution of dilation during D3 through a cross-section of the geomechanical model. (A) highlights the areas of most volume increase (dilation). (B) shows the areas of tensile failure in darker/coloured elements looking north-east during D4.

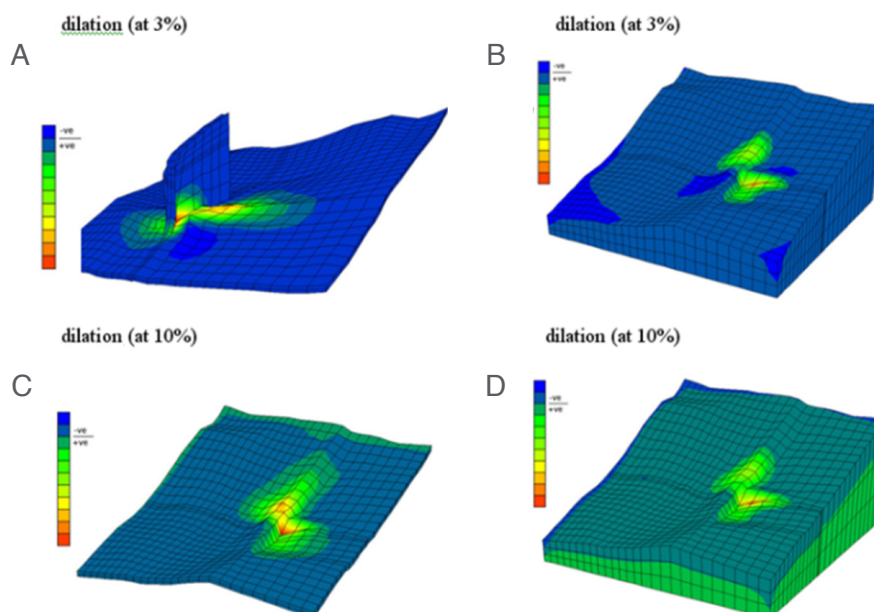


FIG7— Geomechanical modelling with the distribution of dilation around the Dolly felsic porphyry and deeper shear zones consistent with structural and mineralisation models

mineralisation and developed into the 75 000 koz, high-grade Cosmo East lode.

The drilling into the Vogue target returned down plunge and non-reportable intercepts of 23.2 m at 3.69 g/ t Au, 59 m at 3.03 g/ t Au, 9.4 m at 6.29 g/ t Au and 3.4 m at 10.0 g/ t Au (Figure 8). This indicated that the target was valid and had the potential to host a significant mineral resource with economic grades and width. Of equal importance, the intercepts highlighted the existence of a domain of mineralisation that may be conducive to larger-scale mining than the predominantly narrow stopes being mined in the Sunrise Shear, Watu Astro and GQ lodes. However, the orientation, geometry and dimensions remained undetermined.

As a consequence of this drilling and additional drill holes into the target area, which returned additional gold-bearing intercepts, deep drilling platforms were designed and planned by exploration geologists and the medium-term planning engineer. These were designed to initially develop on lode of the base of the Dolly mineralisation to appreciate the nature of the mineralisation and to offset the cost of the development. From here, an additional 700 m of drilling development was established 350 m west and south of the intercepts. The additional underground diamond drilling from the new infrastructure highlighted an undifferentiated and mineralised domain in excess of 40 Mt and unconstrained high- and low-grade domains exist. This required an extensive, systematic and coordinated drilling and sampling program from surface and underground positions, which formed the heart of the mine life expansion studies. Due to the success, scientific justification and support, substantial Sunrise Dam-specific exploration budgets were approved, but the scale and timing required a different approach than conventional drilling and development strategies that had previously been employed.

The concept of innovation here refers to making changes in established practice, especially by introducing new methods, ideas, processes or products.

Research and development are two components of innovation. These activities are the 'convergent steps' in innovation, where new ways of doing things are explored and implemented. These convergent steps require a strategic

alignment between corporate and operational levels, and a key task is to dynamically provide feedback to ensure that the innovation process is well connected to actual work on projects and operations (Nhoko Phala, personal communication, 2014).

The successful discovery and delineation of the Vogue mineralisation was indeed innovative and 'less conventional' due to the extensive validation of data sets through more advanced and less applied techniques. This was coupled with alternative sampling, applied research and development and probabilistic determinations that have been undertaken. Albeit a deviation from the norm, the recognition of the value it adds to the process is recognised through the discovery and delineation of the complex mineral resource in less than three years.

Vogue is the most significant mineral resource and discovery in the Laverton region and at Sunrise Dam in the last ten years. The geological setting is extremely complex and the variable nature of the mineralisation and high-nugget effect adds to this complexity. Gold mineralisation has variable internal orientations between steep- to shallow-dipping and east-west to north-south strike and is hosted in both shear and fault (breccia-dominated) related structures. Mineral resource delineation and definition was calculated to be expensive and slow if restricted only to conventional drilling methods. It was estimated that in excess of \$100 M would be required over four years to drill the mineral resource out to less than 40 × 40 m.

The early use of the innovative geomechanical modelling paved the way for ongoing innovation as a strategic component of the exploration strategy. This section briefly describes the outcomes of the next drilling phase, whilst also introduces those coincident innovative, sampling and analytical techniques and reveals the outcomes from their application.

In combination with underground diamond drilling, the surface-based, directional drilling and sampling was undertaken with the specific intention to determine the lateral extents of the Vogue mineralisation and whether other deep targets existed to the north. The surface drilling was a timely and important strategy. Not only was it cheaper than

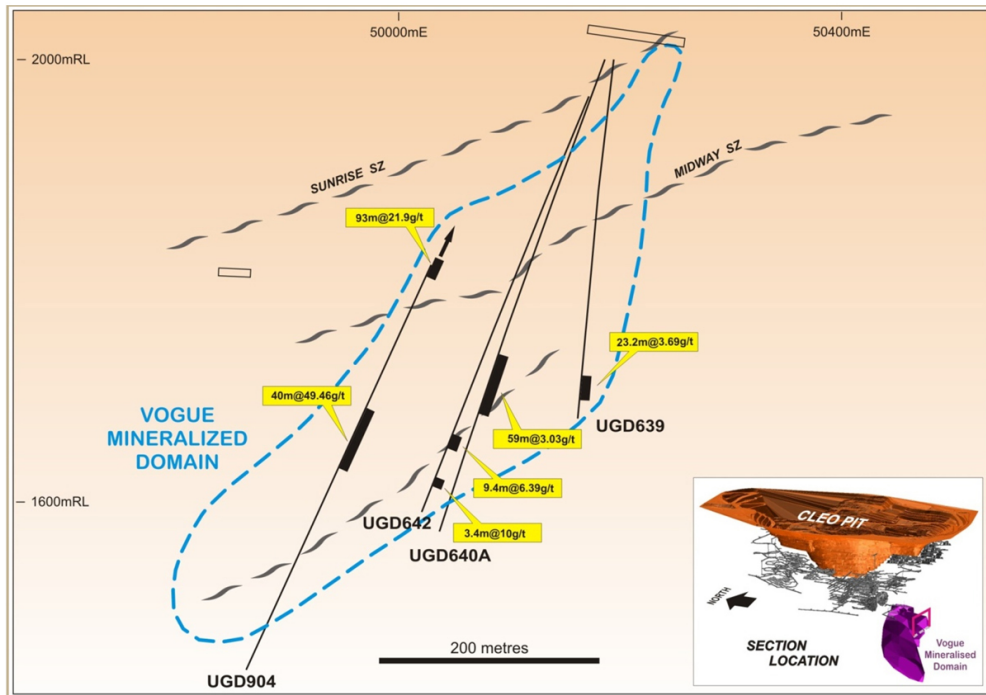
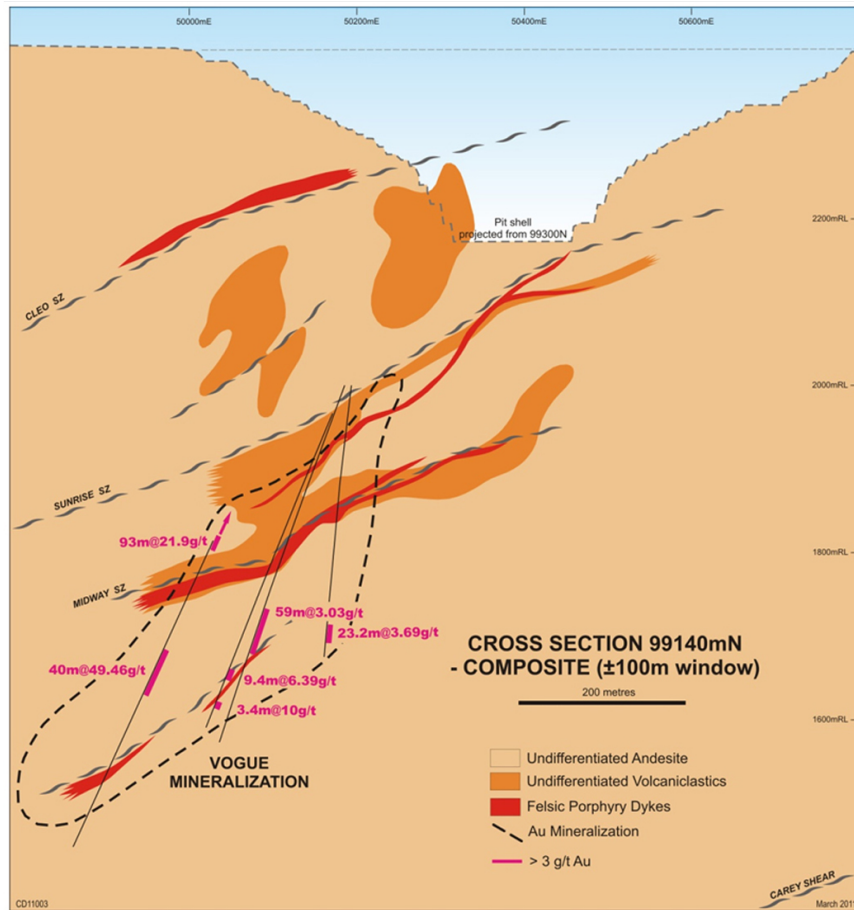


FIG8– Summary east–west cross-section illustrating early suboptimally-oriented drilling into the deep conceptual target (pre-Vogue). Additional follow-up drilling (UGD904) also intersected mineralisation within waste and has therefore not been formally reported in external reports

the extensive capital development required, it also provided immediate structural and assay data for the assessment of the scale of the Vogue mineralisation. The drilling aimed to provide greater scope for the dimensions of the mineralisation and ensure similar errors were not committed by placing capital development through the centre of the mineral resource. In addition to the drilling, a batch sample, collected

from a position proximal to the Vogue mineralisation, highlighted that some processing implication may exist and some test work was required. From a combination of the surface and underground drilling and the development, the following benefits resulted in the next 12 months:

- three type sections were geologically, mineralogically and chemically logged

- the Vogue Inventory was determined to be up to 3 Moz, based on current data
- a central corridor of mineralisation to the Carey Shear was identified
- anomalies in the geometry of the Carey Shear were delineated and modelled with a high degree of confidence
- an initial, though cursory, geological and mineralisation model was produced
- an inferred Mineral Resource estimate on Vogue was completed (~7.2 Mt at 3.5 g/t – 820 Koz Au)

- recognition that metallurgical variability within the mineralised domain exists
- development of multidimensional, multidomainal models that result from coincident sampling and collaborative investigations.

The mineralisation remains open to the south and at depths beyond 1.2 km vertical (Figures 9 and 10).

Differentiating appropriate Vogue domains to both appreciate the variable nature of the mineralisation and ultimately assist mineral resource evaluation, the following

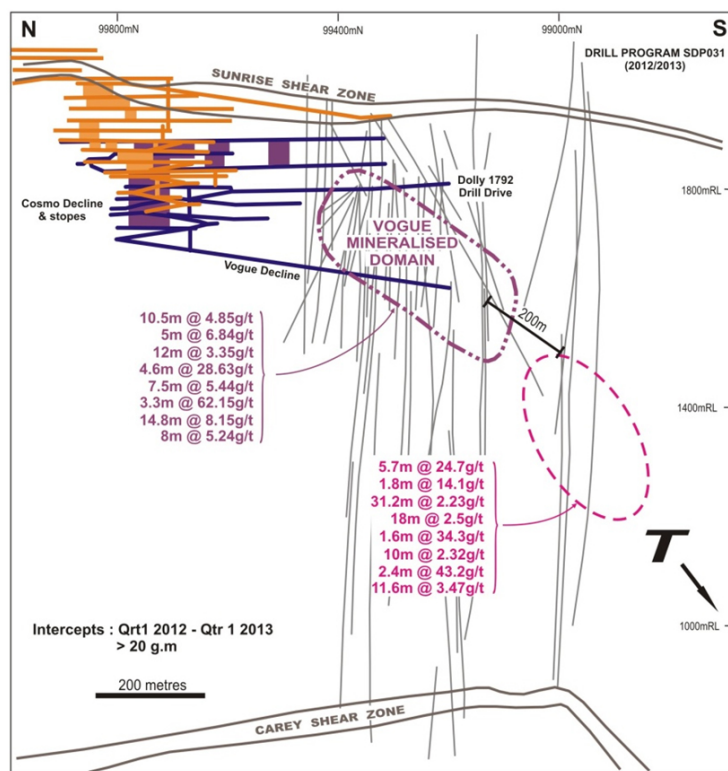
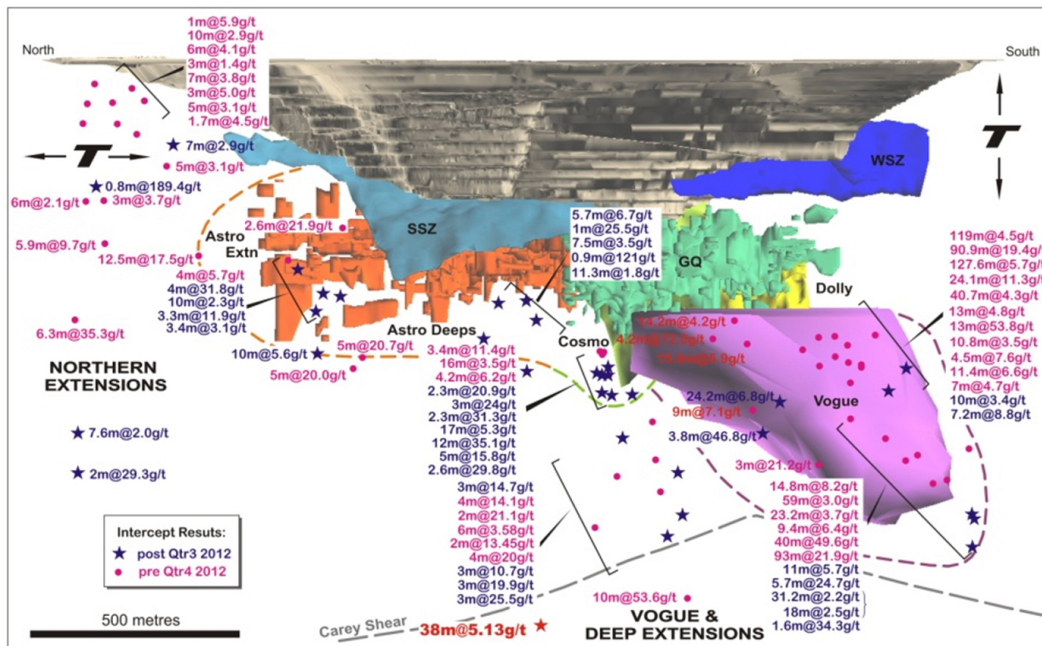


FIG9— Composite longitudinal section through Sunrise Dam (looking east) that shows an open pit profile with key underground crevices and targets. The recent drilling intercepts resulting from this exploration strategy that are visible in this plane are illustrated. The drilling intercepts into the Vogue domain (in the south) and the central corridor that tested the structural and fluid/mechanical modelling validated the existence of several concentrations and new domains of gold mineralisation beneath the Sunrise Dam deposit.



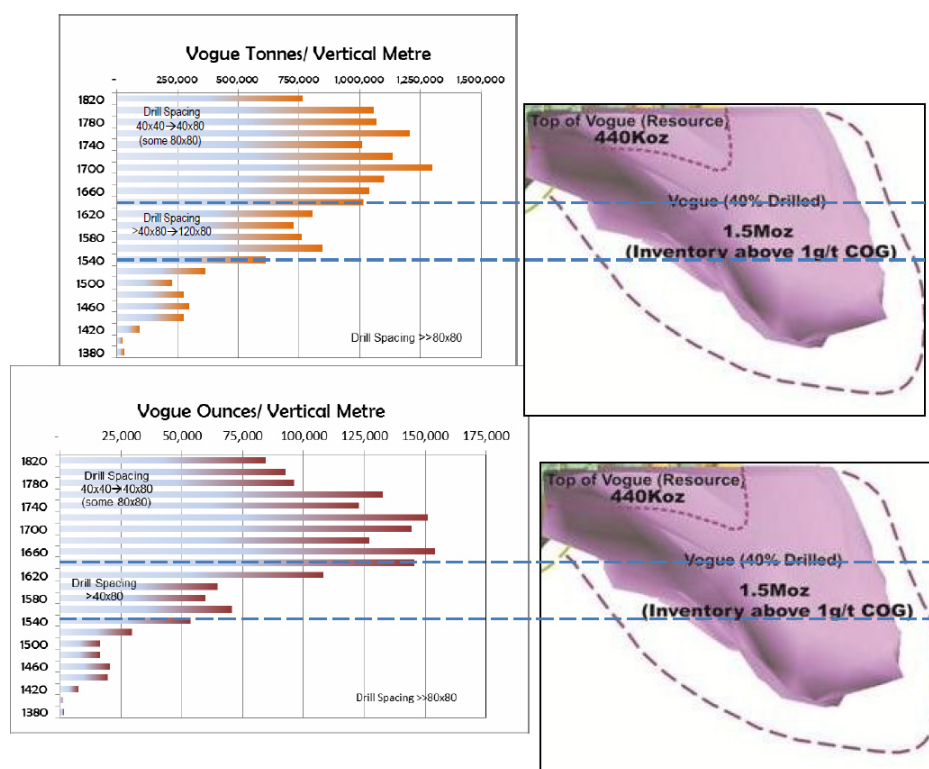


FIG10— Spatial and vertical representation of Vogue inventory and relationship to the extent of drilling through a north-south slice through the mineralised domain. Refer to Figure 9 for scale.

innovations were undertaken and collaboratively integrated in combination with a second and complex drilling phase:

- mineralogical investigations and geochemistry, which included geochemical sampling and analysis, hyperspectral analysis and portable X-ray Fluorescence (pXRF)
- mineral and chemical characterisation
- alteration mapping and modelling
- conditional probability modelling
- mineral resource estimation and preliminary geometallurgical profiling and domaining.

Some of these are currently being undertaken and are not yet complete. However, with an integrated and holistic data collection strategy, this can continue without significant impact on the schedule and be incorporated into the predictive planning and scheduling for the mine.

### Mineralogical investigations and geochemistry (hyperspectral and portable X-ray Fluorescence)

It was evident that the Vogue mineralisation was an extensive domain that was complex and difficult to interpret with confidence. To that end, rather than just gain a natural and better understanding of the lode geology from additional drilling, an alternative strategy was devised to use the information and details from previous sampling and develop several coincident models that would enable a cumulative knowledge growth and enable alternative applications for a holistic understanding that could feed into the work processes of other departments.

### Geochemical sampling and analyses

Approximately 75 000 pXRF samples have been collected since 2012, when the pXRF program commenced at SDGM. All analyses were undertaken on pulverised material returned after laboratory gold fire assay analysis. Two Olympus InnovX Delta pXRF instruments are used. The data collection process

has been refined over time, moving from normalisation to a single standard system to calibration using multiple standards that better represent the main lithologies present at SDGM. Both instruments have also had new analytical modes installed, which allow a broader suite of elements to be analysed.

A robust quality assurance/ quality control protocol is in place, with routine analysis of blanks, repeats and standards at regular intervals during an analytical session. Each session comprises four to six hours (>100 analyses). Extensive test work was undertaken to establish optimum conditions for analysis. This supports robust post-processing of data and minimises drift. A subset of samples are analysed for a multielement suite by laboratory methods (lithium borate fusion, XRF and ICP-MS/ OES). Comparison of laboratory and pXRF data shows good correlation ( $r^2 > 0.95$ ) for all elements of interest. All data collected is thus considered fit for purpose and for inclusion in JORC-compliant Mineral Resources (Figure 11).

The geochemical data collected by pXRF has been used to improve models of the Vogue orebody and associated geology and alteration. A litho-geochemical schema was developed using immobile elements (Cr, Zr and Ti) to identify groupings, including andesite, dacite, porphyry, basalt and komatiite. This objective approach minimises the effects of subjective logging by individuals, resulting in increased confidence in the position of boundaries that can be obscured by alteration overprints (Figure 12).

### Mineral and chemical characterisation

The pXRF data has also been used to interrogate geometallurgical test work results. Whilst it has not yet been possible to determine exact proxies for geometallurgical groupings within the Vogue domain, associations with arsenic and bismuth have been noted, which allow domaining of complex ore types from the ore most suited to processing at SDGM. This approach is currently being investigated further for use in mine planning and scheduling. Microcharacterisation of ore samples from

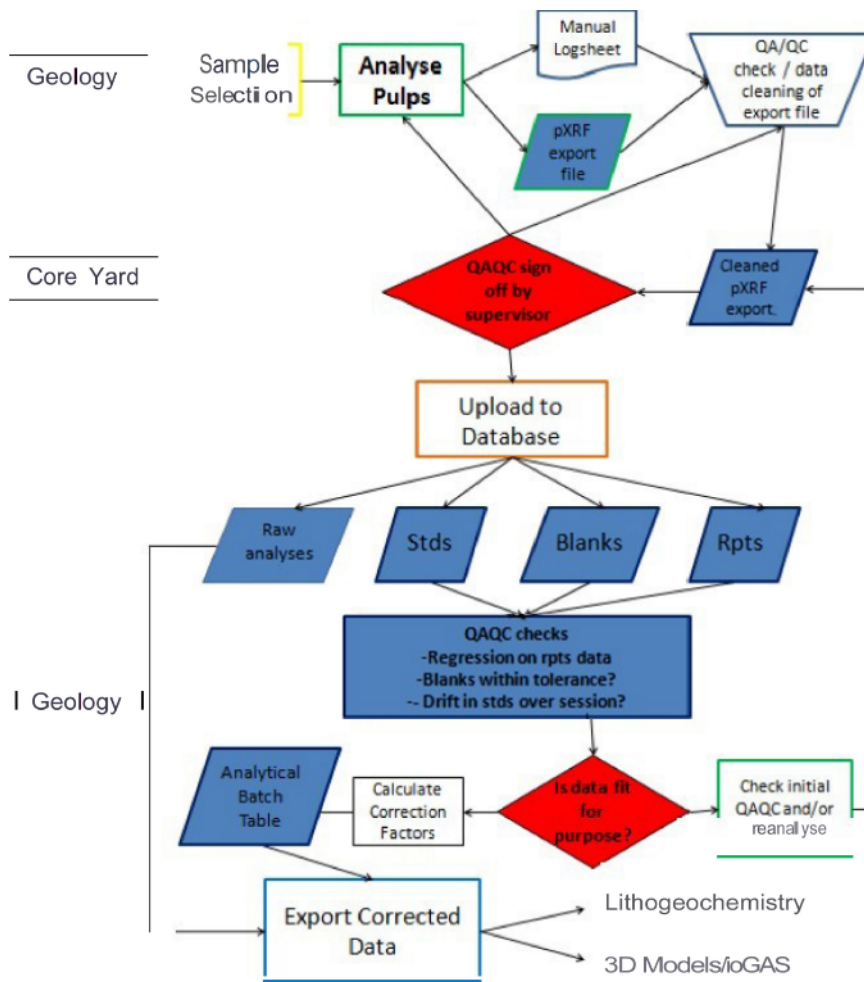


FIG11—pXRF Workflow at SGM

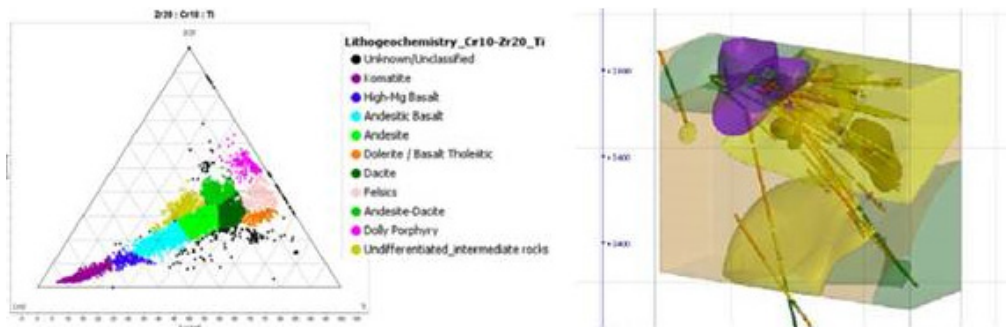


FIG12—The 3D lithogeochemical classification of Vogue using portable X-ray fluorescence data

Vogue further indicates the importance of understanding the arsenic and bismuth association with an increasing volume of tennantite and tetrahedrite inclusions within pyrites in samples containing >10 g/t Au. In samples with gold grades greater than 100 g/t Au and high bismuth content (>100 ppm Sb), gold has been observed to be encapsulated by aurostibnite and bismuth-tellurium-gold overgrowths, which are likely, at least locally, to negatively impact recovery.

**Mineral and chemical characterisation**

X-ray diffraction analysis of samples from a drill hole intersecting Vogue mineralisation found that potassium content in andesites, measured by pXRF, could be used as a direct proxy for sericite alteration abundance. A shift in carbonate composition from calcite to dolomite around high-grade gold intercepts was also noted. A similar

trend is noted in hyperspectral analysis, indicating that this association could be modelled in 3D.

**Hyperspectral core imaging**

The hyperspectral core imaging (HCI) technique applied at Sunrise Dam used a push-broom hyperspectral camera to produce a raster image of diamond drill core, where each pixel represents a spectrum across the short wavelength infrared (SWIR) range. The imagery has a pixel size of approximately 1.6 x 1.6 mm and spectral resolution of 7 nm. The high spatial resolution and complete coverage of the core’s cut surface represents the mineralogy well in the core and delivers this with spatial context. Minerals such as sericite, chlorite, dolomite and calcite are diagnostic of greenschist facies orogenic gold deposits and are responsive within the SWIR spectral range. In addition, the high spatial resolution of HCI

lends itself well to measuring vein-hosted and often narrow mineralised systems such as Sunrise Dam.

HCI was employed at Sunrise Dam for two primary reasons. Firstly, it is a method to objectively measure alteration minerals, with some information, such as sericite chemistry, being beyond the scope of the human eye. Secondly, the alteration enveloping the mineralised structures is both more consistent and has a broader spatial footprint than the gold geochemistry. This suggested that the ore shoot geometry could be modelled with greater reliability and accuracy through objective alteration mapping than by using the nuggetty gold geochemistry alone. In addition, the technique allows broad domains of mineralogy, which could relate and have implications to mining and processing, to be differentiated.

Approximately 96 000 m of halved diamond drill core was scanned across two campaigns using a SpecIm sisuROCK hyperspectral imaging system. The drill core was from the Vogue, GQ and Cosmo East domains. On average, 2500 m of drill core were scanned each day, meaning that high volumes of core were worked through rapidly. After data corrections had been applied, the image data was interrogated and mineralogy of the alteration system around the lodes was characterised. This data exploration process formed the basis for the design and creation of spectral products that specifically targeted minerals useful in delineating ore shoots at the project.

Within the GQ domain, which had been the focus of HCI interpretation at the time of publication, measurements of sericite composition and abundance, carbonate composition and chlorite abundance all demonstrate a statistical and spatial relationship with the few well-defined mineralised structures. However, on their own, none of the spectral mineral products consistently define the geometry of the lodes to a confidence level capable of impacting exploration or mining at the operation. Thus, the four most robust mineral products were combined into a single alteration index, indicating alteration intensity and, in essence, probability of being mineralised.

By integrating the HCI products with auxiliary data (gold assays, lithology and other hyperspectral layers), structural trends were recognised in 3D and used to guide modelling of the alteration index within the Leapfrog™ software. The resultant alteration block model and wireframes provide a data layer to inform multiple processes at the mine, including exploration targeting, grade control drill scheduling and development placement. The same process of data exploration, alteration characterisation and modelling of the hyperspectral data is in progress within the Vogue domain. Initial results indicate that a similar suite of minerals to that evident in the GQ data will be useful in domaining and delineating mineralisation through Vogue.

Chemical characterisation and discrimination of different domains has become possible through the integrated, dynamic and innovative strategies employed for data collection, rather than retrospective collection and analysis and interpretation. The discrimination of elemental data was undertaken to assist in developing the multiple domain models that can be integrated into geological, geometallurgical and mineral resource estimation models. These are integrated with structural and other geological proxies, all of which should be integrated into future planning for the mine. These assisted in not only developing geochemical characterised domains, but also in re-engineering the original structural and geological model that was the cornerstone of the exploration and discovery process. This has formed the new building

block from which future exploration and mineral resource development will be based.

Using the available chemical data and the renewed knowledge of the domain characteristics, coupled with significant additional learnings about the impacts of appropriate sample type and support from other areas of the mine (Clark and Carswell, 2014), an improved mineral resource to ore reserve conversion within the Vogue mineral resource is likely.

## Alteration mapping

The nature of hydrothermal alteration from petrographic, geochemical, spectral and XRD work was investigated and coupled with underground mapping and core logging. The application and validation of the Mineralisation Code (Nugus et al, 2009) was undertaken and the outcomes are still to be resolved. This work is ongoing. However, initial indications reveal general similarities to the alteration mineralogy and systematics observed within the shallower parts of the deposit. Variations that are yet to be fully explained include silica-garnet domains and replacement pyrite domains at deeper levels, with disseminated sulfides and mineralisation in steeply-dipping, fine-veined stockwork domains.

## Conditional probability modelling

At Sunrise Dam, gold grades measured from samples from diamond core are not representative of the gold content of their host rocks because of the elevated nugget effect. It is common practice at Sunrise Dam to use proxies for mineralisation to help define the limits of the orebody. In the Vogue deposit, we have attempted to automate the use of multielement geochemical analysis as proxies for mineralisation.

The relationship between gold content in a sample and the content of 'non-nuggetty' chemical proxies is not simple, and therefore it is useful to use a probabilistic approach that will provide a measure of the likelihood that a sample is mineralised given its chemical composition. To obtain a suitable proxy, several geochemical elements were combined, which appear to be related to gold mineralisation but have better spatial continuity than gold (Figure 13). A kernel density estimator and Bayes theorem was specifically used to calculate the conditional probability that a sample has an elevated gold content given its geochemical content (Hill et al, in review).

Figure 14 illustrates a diamond drill hole shaded by probability conditioned on three geochemical elements: Cr+Sb+Rb. The Rb and Sb are incorporated in the calculation as they are good indicators of sericitic and sulfide alteration respectively. The chromium is incorporated in the calculation as it is a good indicator of primary rock type (which also affects the likelihood of mineralisation). The spatial continuity of the proxy is substantially higher than

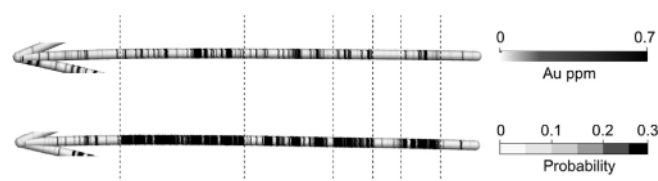


FIG13– Diamond drill hole UGD2189 shaded according to Au assay values (top) and conditional probability of Au (using Cr+Sb+Rb). Using the probability values we can divide the drill hole into regions that are more likely to contain continuous mineralisation, patchy mineralisation or non-mineralisation (dashed lines).

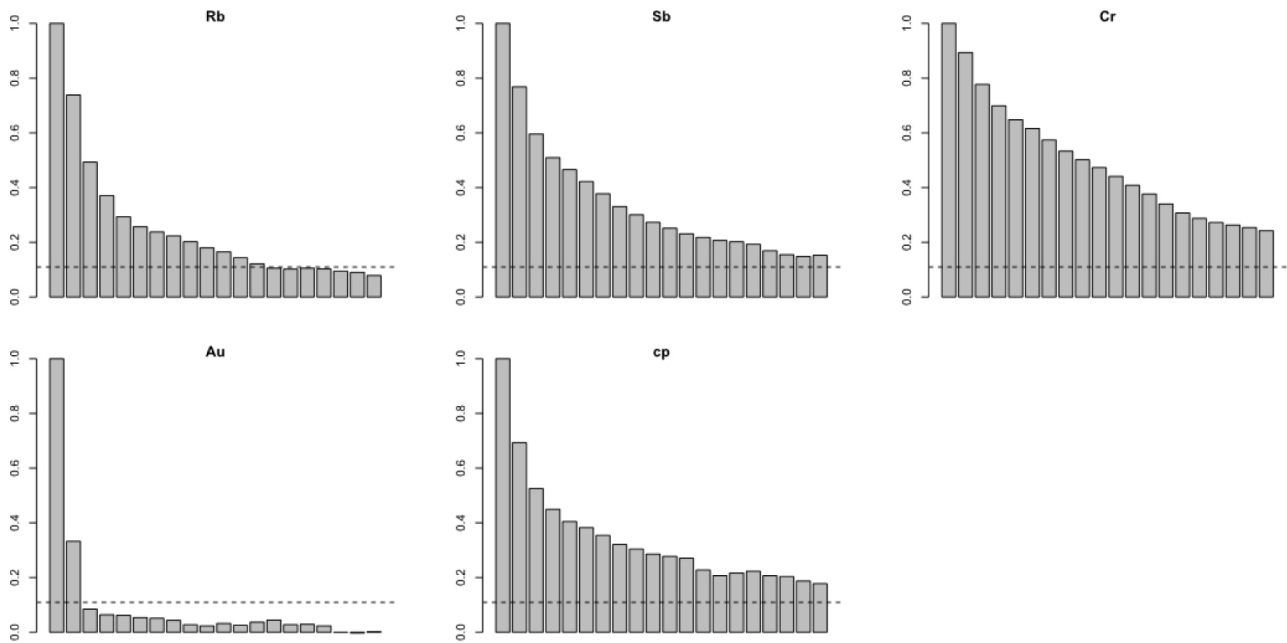


FIG14 – Autocorrelation plots of (top row) Rb, Sb and Cr and (bottom row) Au and conditional probability (cp). Plots show mean auto-correlation values for 15 drill holes. Minimum lag distance is 10m and maximum lag shown is 200m. The dotted line is the 95 percent confidence interval.

that of the gold assays, as shown by the autocorrelation plots in Figure 13.

The advantage of using conditional probability values in the interpretation of the orebody boundaries is that it provides us with a greater level of confidence than using gold assays alone. In addition, automation and quantification of the proxy removes the possibility of personal bias when the geochemical elements are manually incorporated into the orebody modelling by the geologist.

### VOGUE GEOLOGY AND MINERALISATION

As a consequence of the innovation and exploration strategies undertaken specifically for Vogue, not only has a significant mineral resource been delineated, but a detailed understanding of the Vogue geology and the key geological domains that impact the mineral resource estimate (gold

grades), in conjunction with the mineralogical and chemical distribution throughout the Vogue area, now exists.

The Vogue mineralisation and mineral resource is the single largest mineral resource in the SDGM inventory, and it is located in the southern end of the mine, 600 m below the base of the open pit (Figure 15). It extends from the Dolly and Cosmo mineral resources and is contained within a 400 × 350 × 500 m domain to the south-east of the current mine area. The current Vogue preliminary and planning estimate is 885 000 oz, with a total current mineral inventory estimated to be in excess of more than 2.5 Moz. The mineralisation is currently open to the south, north and at depth.

As expected, Vogue is a complex geological domain that contains a myriad of altered volcanic and clastic rocks, redistributed by a complex array of individual structures that

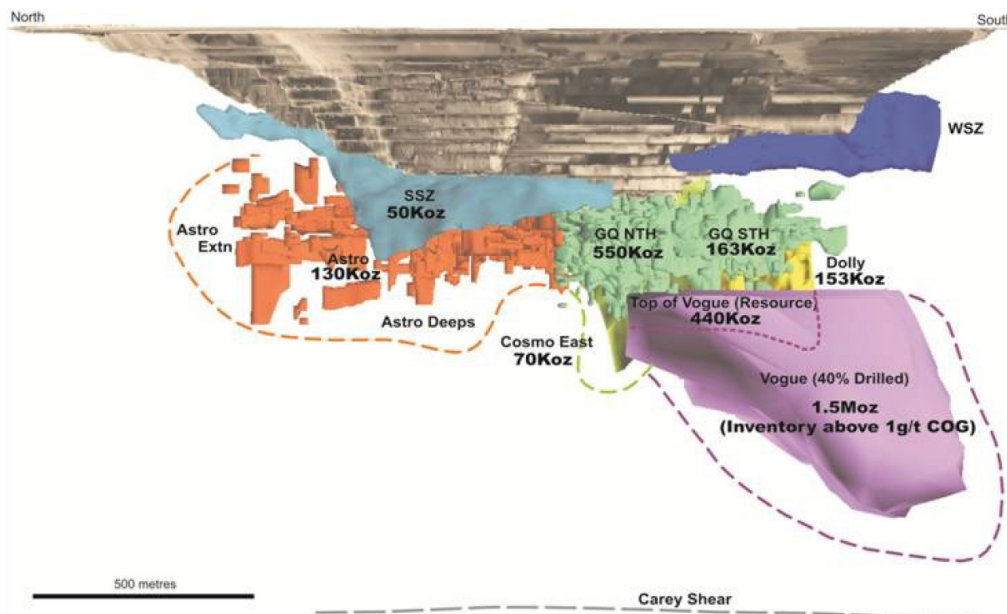


FIG15 – Composite longitudinal section through the Sunrise Dam gold mine, illustrating the location of Vogue to the south (south-west) and other residual resources

are developed within a predominantly south-west-dipping fabric that is consistent with the S3 cleavage defined by Nugus et al (2005) and Blenkinsop et al (2007).

The Vogue stratigraphy is consistent with the SDGM lower stratigraphic package insofar as it is dominated by volcanic and volcanoclastic rocks of intermediate affinity. The andesitic rocks are aphanitic and porphyritic and typically dominated by plagioclase, remnant amphibole, chlorite, illmenite±magnetite and quartz. They vary from basaltic to quartz-rich, whilst the volcanoclastic rocks are immature and are reflective of proximal autoclastic breccias and conglomerates. The volcanic package is overlain by chemically distinct and barren ultramafic dykes to the west that defines the hanging wall and upper (western) boundary of the Vogue mineralisation (Figure 16). These are integrated and transposed by the D1- and D3-generated Midway Shear Zone, which hosts the ~1.5 Moz GQ mineralisation.

The rhyolite-porphyry dyke that intrudes the volcanic and metasedimentary sequences does not consistently cross-cut the lower volcanic rocks. Instead, it is dragged into a hanging wall shear and folds to the west before it is either transposed or faulted out.

The deformation history around Vogue reflects at least two stages of folding and hydraulic fracturing that overprint shearing. Some of the fabrics develop as a consequence of shearing and cleavage development. These generate several plunge directions for the mineralisation and create an additional level of complexity to the orientation and

geometry of the mineralisation. This has been modelled and is illustrated in Figure 17.

In plan view, the folding of the felsic porphyry dyke is an obvious feature that controls and concentrates a significant proportion of gold mineralisation in the upper areas of the Vogue domain. This is represented as an open, west-plunging fold that closes to the south-east. The western limb is missing and proposed to be faulted off. However, this could have been transposed during subsequent shearing during D3 and D4. The axial surface to the fold is reflected as a strong north-west- to north-north-west-trending cleavage that develops a penetrative fabric throughout the entire Vogue domain. This cleavage is refracted through the felsic porphyry or may indicate subsequent movement on the contacts between the felsic and andesitic volcanics (Figure 18).

The Vogue domain lies immediately footwall to the south-eastern extension of the mineralised Midway Shear Zone (Figure 16). In the areas immediately proximal to the HW Midway Shear, the predominant foliation is directly associated with mineralisation and is preferentially oriented parallel to the Midway Shear Zone, which dips approximately 40°–50° towards the south-west (220°). With distance from the HW contact, the general orientation of the foliation is steeper (55°–60°) and dips towards 240°. This more closely parallels the axial surface of the folded porphyry (Figures 17 and 18). The higher-angle structures, which also contain breccia textures, are predominantly/ preferentially oriented north-west to north-north-east, indicating development during

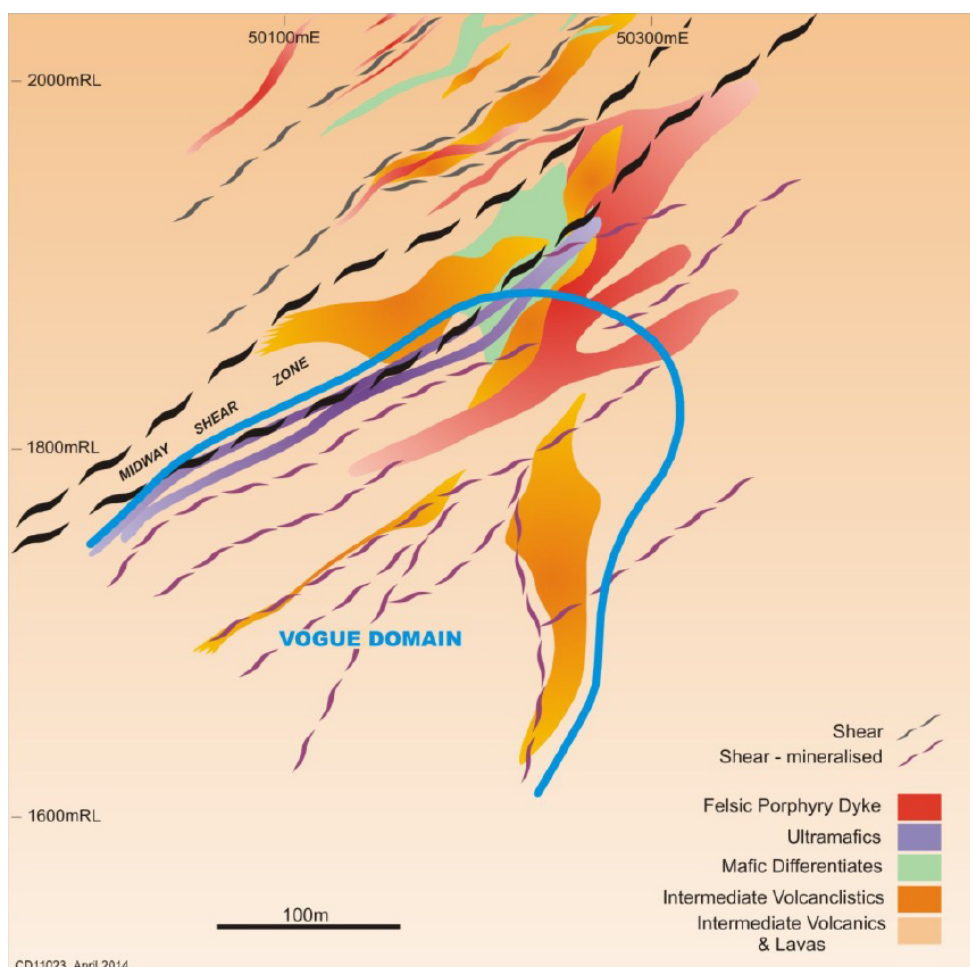


FIG16– East-west schematic geological cross-section through the Vogue mineralisation. The Midway Shear marks the HW boundary, and steep and shallow-dipping orientations exist within undifferentiated volcanics and volcanoclastics

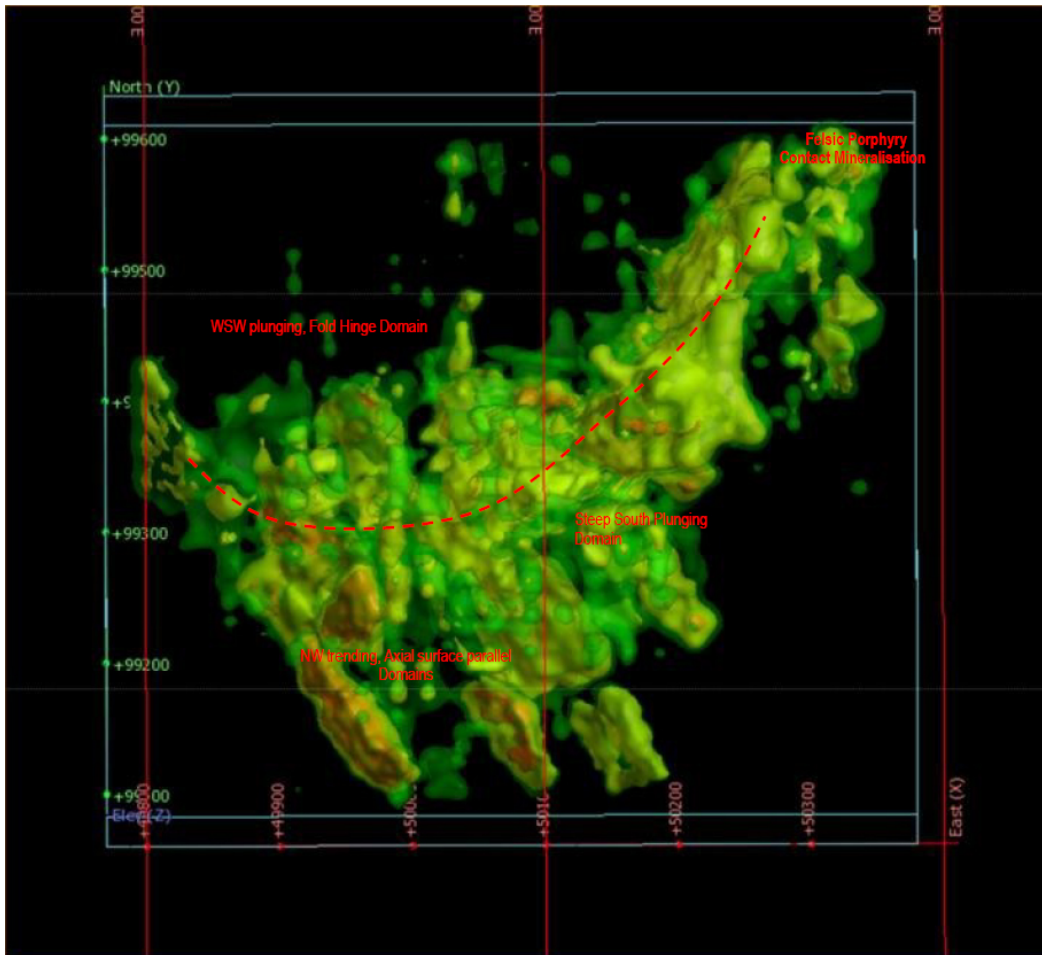


FIG17— Plan view of the Vague mineralisation that illustrates the complex geometries as a consequence of the associations with the felsic porphyry contact, the fold closure, steep south-plunging intersection pipe and the steep fold lines that are axial surface parallel.

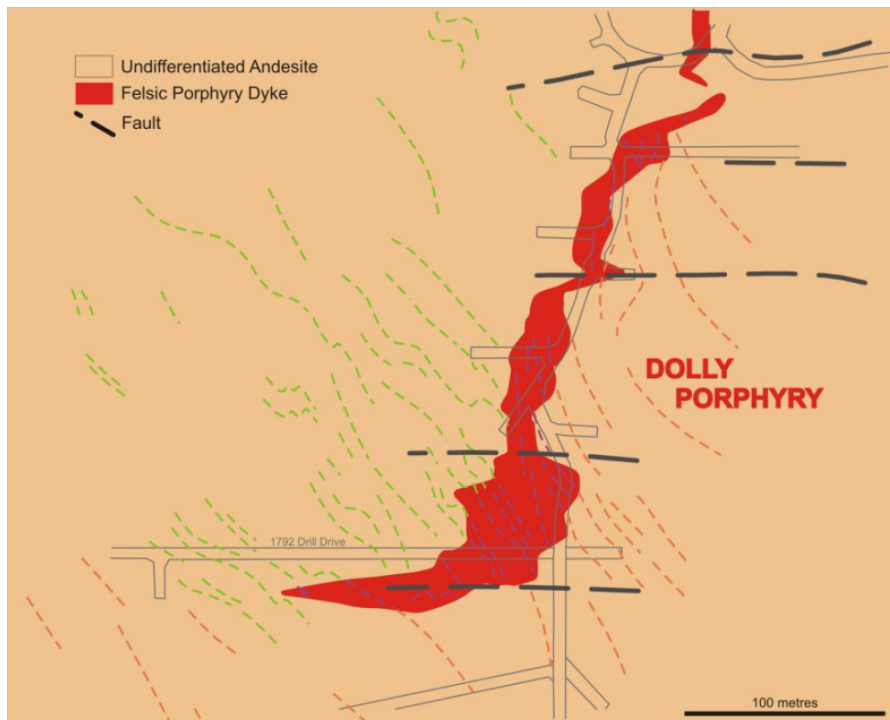


FIG18— Plan view of the Vague domain at 1800 RL, illustrating the basic geology and deviations in existing and developed fold orientations that are generally associated with mineralisation. The predominant orientation is north-west–south-east and is axial planar to the folding of the dyke. It is also locally distorted around the felsic dyke, which may be a consequence of either refraction through the less competent felsic dyke or drag from faulting that has developed at the contact with the surrounding volcanic rocks.

north-east shortening coincident with D3 and D4 deformation (Nugus et al, 2005; Blenkinsop et al, 2007).

Gold mineralisation is primarily vein-hosted and developed within the shear and breccia domains that are shallow and steep-dipping and form a ‘mega-stockwork’ that localises higher-grade concentrations of mineralisation into specific domains within fold hinges and at intersections with the axial surfaces and the felsic unit. Outside these domains, mineralisation is more sporadic and is contained within localised domains that are dominated by narrow and discrete veins that form a broader stockwork. The high-grade gold mineralisation at Vogue is concentrated at the sheared litho-structural contacts and in the fold closure of the felsic porphyry. The mineralisation in the Vogue area does not appear to extend above the Midway Shear. It does, however, extend to the west near the SSZ.

The overall localisation of the main mineralisation within the upper Vogue domain is almost certainly due to dilation and the concentration of fractures and shears around the nose of the Dolly fold, coupled with higher shear strains along the Midway–maße package. The deeper sulfide-rich material is mostly foliated with local high-strain domains that have an obvious concentration of veins and a penetrative fabric (schistosity), suggesting it is connected to the foliation-parallel style of mineralisation within Vogue, rather than being solely oriented within the steeper faults and foliations. These main lodes have also concentrated through the intersection of the steep foliation (cleavage?), (~50°–80°/ 260°, 80°/ 230°) and Midway Shear-parallel foliations (~50°/ 220°). These varying controls that concentrate mineralisation result in vein-rich domains and shoots that develop in orientations that either plunge moderately west-north-west or steep towards the south.

In this regard, Vogue is similar to Cosmo, Astro and other steep-dominant lodes with south-plunging shoots that also appear to be the intersection of north–south steep breccia veins with moderate/ shallow west- to south-west-dipping gold-bearing foliated rocks and/ or contacts in similar orientations (Figure 19).

Of significance is the anomalous geological discriminator for the Vogue mineralisation. It is concentrated within and immediately proximal to the major volcanic intrusive domes and is not specifically concentrated at lithological and lithofacies contacts as are almost every other lode at Sunrise Dam. This is highly likely to be the major reason for the diffuse, broad and less concentrated nature of the gold

mineralisation when compared to key lodes within the upper parts of the mine (eg Cosmo, Western Shear, Sunrise Shear, GQ etc). This may have implications on the concentrations of gold and associated metals (arsenic, antimony etc) and also the manner in which it may be eventually mined.

The gold mineralisation commonly contains coarse and fine-grained gold associated with carbonate–quartz–pyrite veins. It is common for base metal and arsenic, bismuth and tellurium sulfides to be present, though these are erratically distributed and further work is currently being considered to determine if they will impact recovery. Where disseminated gold occurs, it is contained in carbonate–pyrite-dominated alteration and is probably associated with fine fractures that penetrate into the alteration selvage. The nature of mineralisation reflects that observed in other parts of the mine. The significant difference, however, is that it is collectively developed in the Vogue domain (Figure 20).

The highest gold grades are contained within both shallow (<45°) and steep-dipping domains. Alteration zonation around gold-bearing structures are consistently well developed throughout Vogue and are broadest around the shallow-dipping shear and breccia zones, where they can extend up to several metres from the primary zone of veining.

The shallow-dipping domains reflect shearing with locally intense and penetrative north-west trending fabrics that may be interpreted to be a spaced cleavage that can be mapped throughout Vogue. These are parallel to the major shears within the deposit. In these zones, the gold mineralisation is contained within both shear and breccia veins that have some similarities to the Sunrise Shear and GQ lodes, which contain high- and lower-grade values. The steeper gold zones, however, are commonly isolated individual veins and breccias, locally with a parallel, steep foliation and strike varies from north-west through to north-north-east. These dip between 75°W to 75°E, and there are a good population of steep veins that are parallel to the orientation of the plane containing the best gold concentrations. There is no consistent width to the steeper zones, which are generally <5 m wide. They have very high gold grades and abundant sericite, sulfide etc, and are best described as an anastomosing network of fairly discrete centimetre-scale veins that contain abundant zones of high grade associated with penetrative and variably thick sericite-carbonate-quartz-sulfide alteration selvages. Breccia vein grades drop as they become shallower, suggesting branching out of the fractures and infilling breccias from steep orientations along the foliation, as can

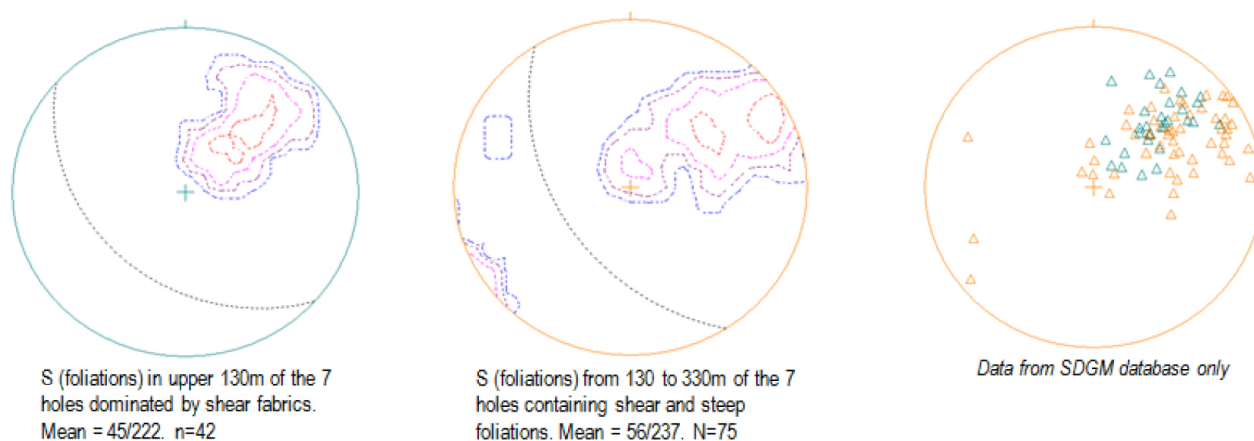


FIG19— Lower hemisphere, equal area stereonetsof foliation measurements and variations in the Vogue mineralisation with increasing distance from the upper hanging wall Midway Shear, illustrating influence from steep structures in the lower portion of the Vogue resource.

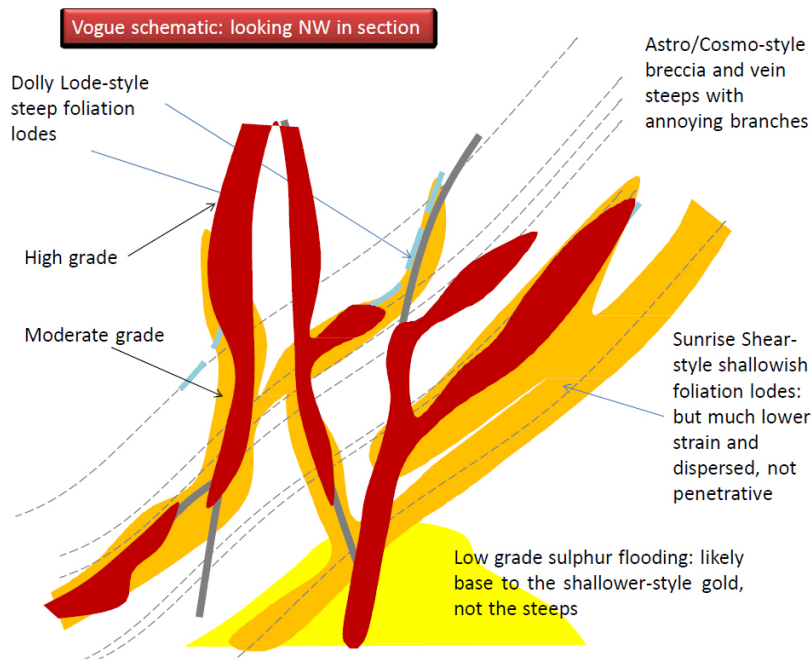


FIG20—Schematic east-west cross-section through Vogue indicating the areas where high grade is concentrated around predominant fabrics

be seen in other lodes (Cosmo, Cosmo East, Astro, Watu etc) (see Figure 11). The overall domain is fairly low strain compared with other lodes. Bands of 0.1–2 m wide moderate foliation are commonly separated by >5 m domains of very little alteration or veining.

Recent advances in the mineralogy of the veins have identified a significant amount of tellurium, arsenic, bismuth and base metals that are associated with late-stage auriferous veins. Cleverley, Nugus and Young (2006) and Sung et al (2007) documented the occurrence of these metals within late-stage auriferous veins in the upper shear and breccia-hosted lodes in addition to early shear veins that are quartz-dominant and generally arsenic-poor and silver-enriched.

For the most part in Vogue, the mineralised veins are enveloped by alteration assemblages consistent with other regions of the mine. However, at deeper levels and in some domains, silica-pyrite-chlorite±garnet are observed, indicating a change in the deposit environment and possibly reflecting an early alteration overprint on the volcanic pile. This is extensively developed at depths greater than 1200 m vertical in the south, and results to date indicate this generally has lower gold grades.

Ultimately, the Sunrise Dam hydrothermal system is driven by the interaction between vertical flow systems, dominated by broad carbonate alteration, and shallow dipping shear zones that acted as mechanical-hydrological seals. There are multiple phases of mineralisation, but critically these appear to be broadly similar except the transition to more base metal, tellurium-rich mineralogy with time. The exact deposition process for the gold is still unknown, but large changes in pressure when the seals become breached probably had an influence. One possibility is phase separation, possibly initiated by exhumation at lithostatic conditions, followed by failure that resulted in fluid pressures approaching hydrostatic conditions (Blenkinsop et al, 2007; McLellan et al, 2007).

## SUMMARY AND CONCLUSIONS

Vogue is the most significant mineral resource and discovery in the Laverton region and at Sunrise Dam in the last ten years. The mineralisation is extremely complex

and is expensive and slow to delineate through conventional drilling methods. It was estimated that in excess of \$150 M would be required over four years to drill the mineral resource out to less than 40 × 40 m. The geological setting is extremely complex and the variable nature of the mineralisation and high nugget effect adds to this complexity.

From existing information, it is evident that Vogue has a realistic opportunity to develop into a mineral resource in excess of 3 Moz. As a consequence of an innovative exploration initiative and process, the Vogue, Sunrise Shear and Cosmo East discoveries have brought forward in excess of 1 Moz in Mineral Resources in the last two years that will continue to grow, and they have been included in the production profile since 2013.

The innovative exploration process promoted specific data collection and interpretations that were validated and modelled through engagement with collaborative expertise. The methods engaged to validate, promote and expand on these data-driven models were a new strategic and innovative initiative that led to the timely and cost-effective discovery of the Vogue mineral resource. With additional data, the original structural and mineralisation model was re-engineered and advanced through extensive sampling, review and geochemical analysis in addition to detailed geological and geostatistical domaining of the Vogue area.

The nature of the work at Vogue has provided an opportunity for cumulative knowledge growth on the existing models, resulting in understanding the ore and waste characteristics, opportunities and risks that enable mineral resource confidence in a reduced time frame and increased involvement from geologists, engineers and metallurgists. The outputs are specifically integrated multidimensional multidomain models rather than an individual model or isolated series of models.

Geometallurgical implications were realised from a small batch sample from which efforts were refocused to undertake mineral and chemical characterisation and profiling (geometallurgy) to re-domain Vogue to understand the structural and grade domains and the mining implications. This made it possible to integrate conditional probability modelling for differentiating preferentially mineralised or waste domains for planning and drilling.



In addition to this, meaningful data has become available early in the decision-making process for mine planners, mine designers and processing personnel. The new methods and processes implemented developed additional new processes and ideas that explain the variability in the mineralisation characteristics, the nature of the chemical signature and its geometry. These would have otherwise remained highly speculative and open to criticism from drilling data alone. These convergent steps were strategically aligned to the corporate objectives.

The altered, innovative and collaborative methods applied at Vogue have directly resulted in:

- shortened time frames from drilling
- reduced cost in capital development and additional mineral resource delineation drilling
- inclusion in the three-year and life-of-mine plan
- a facility to collect and begin data collection for proceeding information (geo-met) at a very early stage.

The process enabled internal communication to appreciate requirements for further data collection and infrastructure to collect more data.

Conventional exploration methods are valid in defining the controlling characteristics of mineralisation and then using them to develop plausible and successful exploration strategies. However, at Sunrise Dam, the nature of the mineralisation and the complexity of the mineralising system, coupled with the necessity to provide a substantial prole to the life-of-mine plan, means that a dynamic and innovative approach was specifically undertaken. The process has now come full circle, with the innovative sampling and collaborative analytics enabling the re-engineering of the geological and structural architecture.

Important questions remain that fulfil the next steps of the process and provide the residual challenges for the mine. These are:

- The relationship between the key mineralisation domains and mine design considering the cost implications of a medium- to low-grade deposit. The opportunity for larger stopes may help this.
- Domains must be transferable to 'mill-recovery' and planning models that integrate geometallurgy.
- Impacts of associated minor metals (As, Sb, S, Pb etc) and the impacts on planning, design and recovery.

## ACKNOWLEDGEMENTS

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