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Exploring for Minerals under Murray Basin Cover with Airborne Gravity Gradiometry

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SUMMARY

In 2021 North Central Gold acquired more than 7,900 line-km airborne gravity gradiometry (AGG), scalar vertical gravity, and total magnetic field intensity (TMI) data over tenements in the Stawell Corridor north of Horsham in north-western Victoria. The purpose of the survey was to improve the understanding of the geology and the prospectivity of the bedrock beneath the cover. The observed gravity gradiometer data has revealed deep-seated Devonian (?) density anomalies in the Cambro-Ordovician bedrock beneath 40m-200m thick Cenozoic Murray Basin cover, providing Stawell Magdala basalt dome-type gold exploration targets. 2D interpretation and 3D inversion of the observed AGG and TMI data have provided structural information and fault information about the underlying bedrock. The survey data have also highlighted the presence of shallow Cenozoic strandlines which provide additional mineral sand exploration targets. The extensive coverage and the uniform quality of the airborne geophysical data has allowed North Central Gold to rapidly identify and focus on specific tenement areas for retention and further exploration.

Key words: Airborne Gravity Gradiometer, Gold, Exploring Under Cover, Stawell Corridor

INTRODUCTION

North Central Gold (NGC) is exploring for gold in the northern part of the Stawell Corridor in Western Victoria. The Stawell Corridor is an approximately 400km long and 15-20km wide, north-to-northwest trending Cambrian to Ordovician basement block.

Western Victoria is known for being an area with the potential for significant mineral wealth but exploration for these deposits been limited by extensive Murray Basin cover which increases in thickness to the north and west. Various abundant gold deposits are known to exist south of the Murray Basin cover, yet the portion under cover remains vastly unexplored and largely untested.

GEOLOGY

Three zones constitute as the Palaeozoic Lachlan Orogen in Victoria, with the Stawell Corridor being the westernmost zone. In the west, the Stawell Zone is separate from the Cambrian Delamerian Orogen (Dimboola Arc Domain) due to the Moyston Fault: an NNW trending, east dipping basal detachment. Note that the larger Bendigo and Ballarat gold fields are hosted in the adjacent Bendigo Zone located in the east. The west dipping Coongee Fault is projected undercover slightly to the east of the NGC tenement area.

The Magdala Basalt materializes intermittently within the Stawell Corridor over a strike length of hundreds of kilometres. The domain of the Stawell Corridor is intruded by Early and Late Devonian granitic plutons. Quartz-rich turbidites and the ~515 Ma tholeiitic Magdala Basalts constitute the Moornambool Metamorphic Complex (Robinson et al., 2006) in the Stawell Corridor.

Due to the Murray Basin cover the Stawell Corridor has only been mapped to a limited extent, with focus on regional-scale features. Hence the Stawell Corridor, which extends into New South Wales from the Victorian border, remains predominantly underexplored.

The Stawell Corridor is well populated with Ordovician to Devonian age mineralization, where exposed. These mineral-rich deposits are hosted by Cambrian meta-igneous rocks and include: Cambrian VMS manifesting as fault-slices within shear zones (such as the Mount Ararat Copper prospect), potential strata-form Cambrian VMS within coherent mafic metavolcanic rock packages exposed adjacent to faults, and Ordovician (Magdala Mine, Stawell; Moyston; Pitfield Plains) and Devonian (Wonga Mine, Stawell) orogenic gold hosted by shear zones developed within – and especially adjacent to – Cambrian mafic metavolcanic (greenstone) rock packages.

However, in the northern section of the Stawell Corridor the gold-bearing Palaeozoic formations are covered by younger Murray Basin sediments. Consequently, only rarely are gold occurrences discovered in that area. The northern part of the Stawell Zone has high potential for undiscovered gold mineralization of several assorted styles, including alluvial and intrusion-related gold deposits. Mesozonal orogenic gold mineralization has accounted for most of historic gold production from the central part of the Stawell Zone and is likely to be the most important geological type of gold mineralization in the northern part of the Stawell Zone under cover.

Prior to 440 Ma, no gold mineralization had yet occurred (Miller and Wilson, 2002), and generally only occurred during the Silurian and Devonian periods. Perhaps the most significant mineralization event in the western Lachlan Orogen – and undoubtedly the largest event – transpired at ca. 440 Ma (Foster et al., 1998). It produced the greatest revenues of gold found in the western Lachlan Orogen (Miller and Wilson, 2002) and occurred in both the Bendigo-Ballarat zones and the Stawell Corridor.

Associated with fault reactivation throughout the Western Victoria (Miller and Wilson, 2002), the next episode of gold mineralization occurred at about 426-420 Ma (Foster et al., 1998) and resulted in significantly less deposits of gold mineralization that the first event (Miller and Wilson, 2002).

The final recognised event of mineralization in western Victoria is the Wonga mineralization at Stawell (Miller and Wilson, 2004). Watchorn and Wilson (1989) suggested that this mineralization has the potential to be spatially and temporally associated with the Stawell Granite emplacement. Miller and Wilson (2004) champion that this final mineralization episode formed at ca. 400 Ma.

Within the area that NCG has tenement, it is hypothesized that hanging-wall reefs – consisting of high-grade auriferous quartz lodes – may share significant similarities – such as occurrence and structure – with those found in the upper levels of the Stawell Magdala mine. During east-west shortening in a muscovite-altered turbidite sequence – which has little prior iron alternation (cf. Magdala deposit), hanging-wall reef mineralisation took place. Herein, the discordant relationship between faults and pre-existing structural fabrics produces the dilation sites and jogs wherein the auriferous quartz veins were formed. This is supported by lithological and structural data. Although these dilation sites are believed to be no larger than 1km, it is more likely that they are found within a 0 to 150-m window, from the tholeiitic Magdala Basalts in the quartz-rich turbidites that together form the Moornambool Metamorphic Complex. As the geological survey implies, layered quartz reefs are inclined to concentrate gold in organic rich wall rock that becomes integrated in the quartz reef as dilation periods occur.

EXPLORATION

The 4Moz Magdala gold deposit in Stawell is the primary exploration model for the purposes of this article. Herein, the gold mineralization occurs in Cambrian meta-sediments that surround a large “dome” structure made of basalt. As basalt is rather rigid – especially in comparison to the meta-sediments that often surround it - these meta-sedimentsare more likely deformed when exposed to pressure. NGC focuses on discovering similar basalt bodies where the contrast in rock competency is greatest, causing ‘voids’ from intense pressure that has allowed quartz veining and gold mineralisation to occur. This exploration process then continues with air-core drilling in the periphery of the basalt complexes, ideally in areas of increased structural complexity. As basalt bodies can be magnetic – potentially containing a remanent component – and are significantly denser than the surrounding meta-sediments, it is expected that the basalt targets should be characterized as moderately magnetic with an associated positive vertical gravity gradient anomaly.

A secondary gold exploration target-style is the Intrusion-Related Gold system (IRG) Wonga deposit model (Bierlein and McKnight, 2005). These exploration target areas are less than 2km from the periphery area of felsic I-type granitic intrusions (Moore, 1996b), and are defined as non-magnetic gravity lows.

In addition, several deposits of strand-line heavy mineral sands have been identified in the Murray Basin. These deposits can be identified as NNW-SSE striking, magnetic lineaments, generally linear and rather narrow and often several kilometres long.

AIRBORNE GRAVITY GRADIOMETRY

High quality magnetic data is crucial for interpreting major structures, intrusives and volcanic units (Moore 1996a, Moore 1997), and as such was seized in the 1990’s by the Victorian Government as per the Victorian Initiative for Minerals and Petroleum (VIMP). Note that key structures within the prospective units are not well imaged by the existing magnetic data. Furthermore, magnetic data may not be suited to Palaeozoic sediments, as they are likely to mineralize in a largely ‘magnetically transparent’ geographical area. Regarding electro-magnetics, this technique was unsuitable as the thick conductive cover can jeopardize electromagnetic surveying, and high-resolution ground gravity data is time consuming to acquire and limited due to ground access issues.

Evidentially, to explore this area effectively, a different method – which still relied on integrated geophysics – was needed. Due to the limiting abilities of magnetics to form images of the target geology – as the cover thickness across tenement areas ranged from 50m-200m – airborne gravity gradiometry was chosen as the survey technique to improve understanding of geology and mineral prospectively beneath the cover sequence.

The Falcon Airborne Gravity Gradiometer was developed by Lockheed Martin and BHP Billiton when the passive submarine navigation technology was declassified in the early 1990's. The Falcon system was designed to measure minute changes in gravity from a moving aircraft, with ~150m resolution and better than 10 Eotvos accuracy.

Falcon AGG has been used from inception as a tool to explore for mineralisation under cover. An early published example of the Falcon AGG (Christensen et al., 2001) involved a series of tests flown by BHP over the Cannington Ag-Pb-Zn deposit. These tests concluded that the FALCON AGG instrument can detect the gravity anomaly from a deposit with the size and geometry of Cannington through 130m overburden. It should be noted that the improvements of the Falcon AGG instrument and processing streams over time now result in data exhibiting approximately half of the 10 Eotvos noise levels reported in the Cannington Falcon data examples.

Previously airborne gravity gradiometry has been employed for gold exploration under Murray Basin cover at Fosterville (Fuller and Hann, 2019), Four Eagles (Burrowes, 2007), and at Stawell (North Stawell Minerals, 2021).

DATA ACQUISITION AND PROCESSING

The airborne survey has a spatial resolution and extent which is equivalent to the data collected from over 130,000 ground gravity stations, and as such is an optimum choice for data collection of this nature.

Over 18 days in August and September in 2021, the airborne gravity gradiometer survey of over 1,500 sq. km. of NGC's tenements totalled, totalling 7,900 line-km flown at 200m line spacing at nominal 80m terrain clearance. High-resolution LIDAR terrain elevation data was able to be recorded simultaneously.

Data noise-levels were low, with 1.6 Eotvos RMS error on the curvature gradient components. These corresponded to a 3.2 Eotvos RMS error on the derived vertical gravity gradient G_{DD}. The derived digital elevation model was used to terrain correct the AGG data, assuming an optimized terrain density of 2.0 g/cm^3. Figure 1 shows the resulting vertical gravity gradient component, following re-processing to minimize noise whilst keeping resolution.

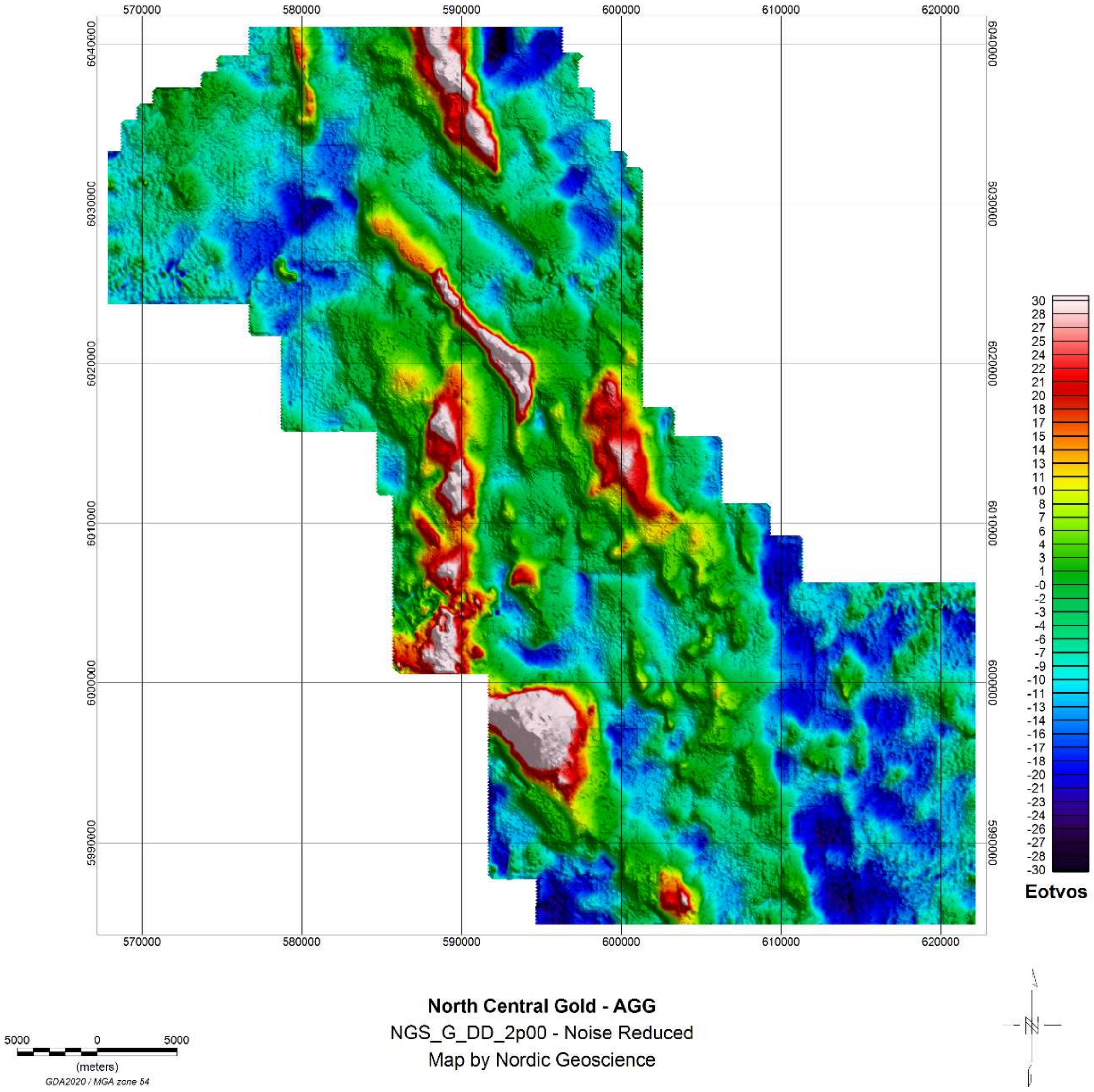

Figure 1. Vertical gravity gradient component G_{DD}

Almost all of the G_{DD} anomalies fall within the [-30Eotvos; 30Eotvos] range. Herein, the regions of bands of higher gravity gradient values indicate the presence of volcanic and volcaniclastic units. Note that the strong gravitational lows generally correspond to felsic intrusions, and areas with little gravity gradient signal are associated with deep water turbidite meta-sediments.

Magnetic data was also acquired during the surveying and Figure 2 shows the high-pass filtered reduced-to-pole Total Magnetic Intensity (TMI) data.

The TMI data shown in figure 2 has a range of ~300nT. The magnetic anomalism is primarily associated with Cambrian/Ordovician-aged volcanic stratigraphic sequences and with localised Tertiary-aged igneous plug-like mafic intrusions. The magnetic intensity falls off from the older more magnetic units in the west to the younger meta-sedimentary units in the east. Some volcanic units display properties of reverse magnetic polarisation. The TMI survey data also demonstrates the presence of shallow Cenozoic strandlines that contribute additional mineral sand exploration targets.

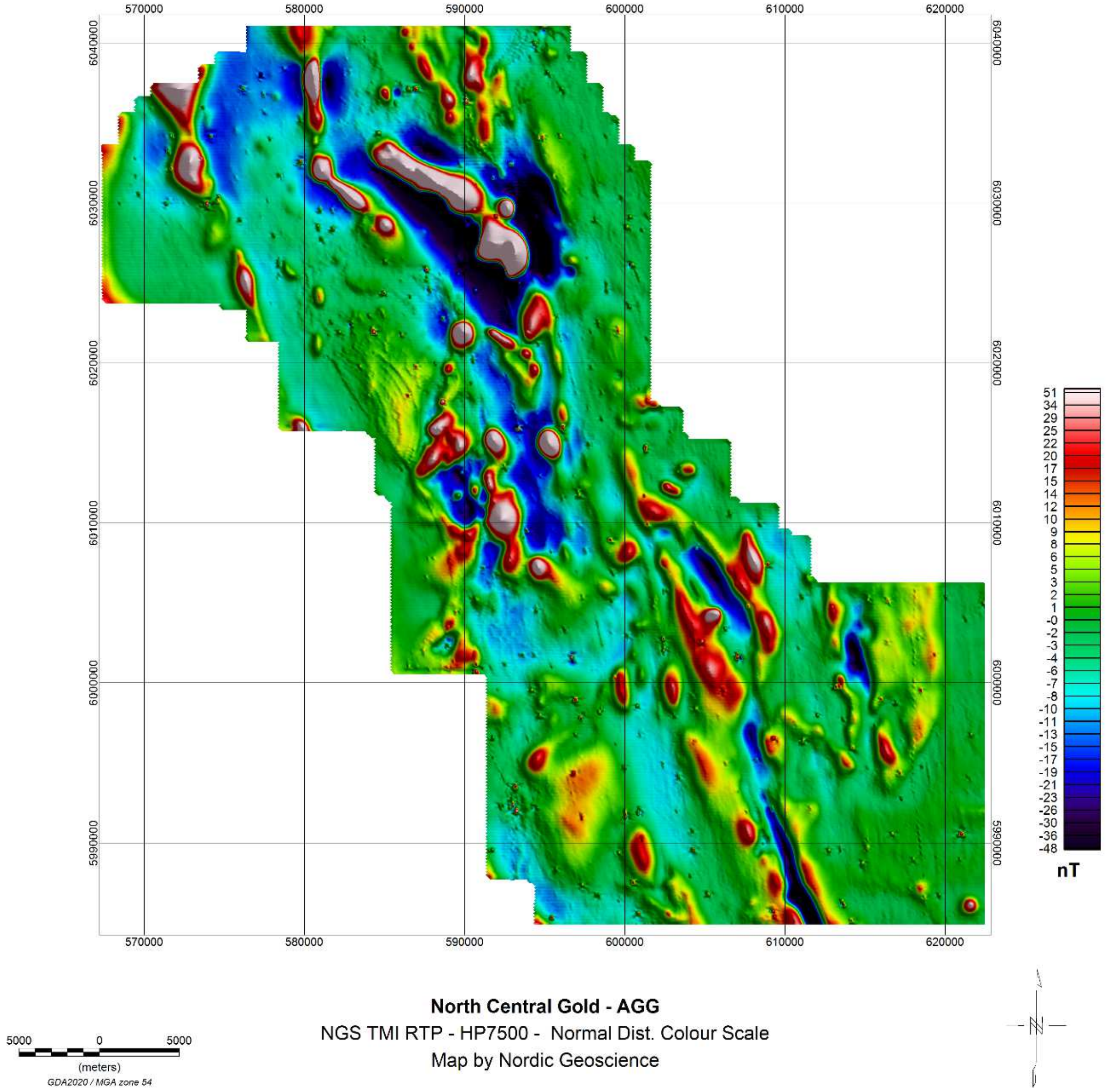

Figure 2. High-pass filtered reduced-to-pole (RTP) Total Magnetic Intensity (TMI) data

DATA INTERPRETATION

Multi-scale edge detection (Archibald et al., 1998) was used on the potential fields data sets. This allowed for first-pass insight into both the orientation and location of any major litho-boundaries in the survey area.

This information – coupled with information regarding any regional deformation history – was combined into an analysis of the structural evolution of the geological units present in the survey area. This interpretation is separated into three distinct phases:

1. Early ~NE-SW oriented ductile shortening (D1-3) produced a broadly ~NNW trending system of structures that precedes any mineralisation and is represented by crustal scale thrusting and tight upright folding in the Delamerian deformation.

2. Two major episodes of brittle deformation (D4-5), including offset earlier deformation during rotation of strain from E-W to NW-SE, and potentially some sinistral wrenching, reactivated. It is likely that mineralisation transpired between D4 & D5 during rotation of strain, and/or at the end of D5. This resulted in ~NW-SE oriented structures offsetting D1-3.

3. A set of dominantly NE-SW as well as NW-SE faults appear to offset earlier D1-4 structures, and likely occurred during further rotation of the strain field to ~NNW-SSE shortening.

Figure 3 shows the final structural interpretation of the airborne gravity gradiometer and the total magnetic intensity data sets.

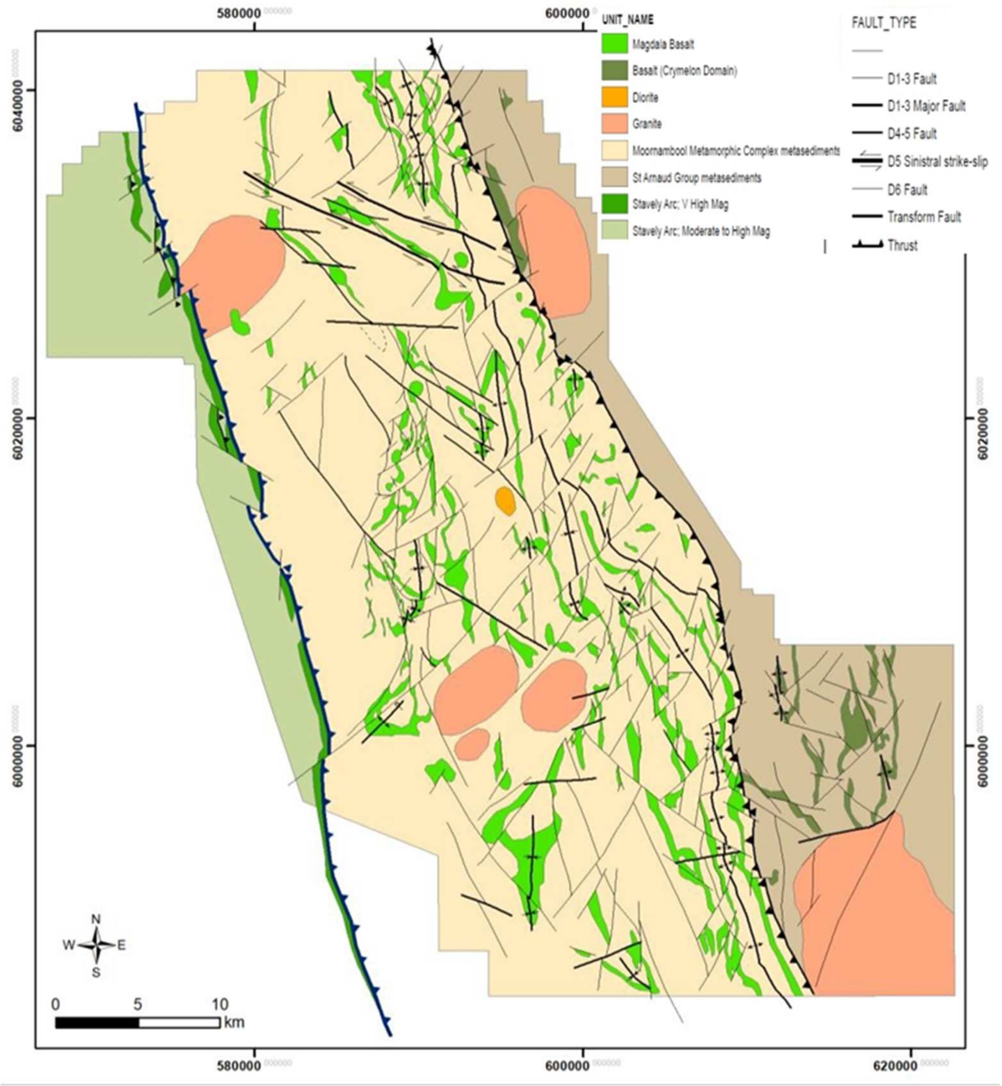

Figure 3. Final litho-structural interpretation

DISCUSSION

The interpretation of the litho-structural data supplied has allowed for the identification of target zones within the survey area. These ‘target zones’ are founded on the structural controls derived from the multi-scale edge detection, character of the geophysical signals, the intensity of structural complexities, and on implied lithological criteria – primarily proximity to basalt structures.

The acquisition of high-quality, high-resolution data from the airborne gravity gradiometer survey has allowed for the creation of high-quality interpretation products. Consequently, both geological and structural understanding has improved, in addition to the generation of 1,960 first-pass gold targets for follow-up algorithm-based workflows. Furthermore, the survey data has promoted the identification of potential heavy-mineral sand strandlines and paved the way for future identification of select areas for retention and narrowing the subjects for further exploration.

NCG has exercised the ability to prioritise their exploration workflow under deep cover in a cost effective and efficient approach, thus allowing systematic exploration to be accordingly explored. Herein, NCG’s successful efforts promotes the benefits of providing a measurement of a different physical property – density, as opposed to electrical conductivity or magnetic susceptibility.

Due to the success of the 2021 Falcon AGG survey, in 2022 NGC acquired additional AGG data over the remainder of the tenement holding in Western Victoria. This non-invasive approach thus enables NCG to place a focus on exploration efforts and make quick decisions regarding the tenements. Simultaneously, NCG will minimise ground disturbance ground access, both of which are integral aspects of NCG's social licence which allows the company to operate in such an ecologically sensitive area.

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REFERENCES

Archibald, N.J., Gow, P., and Boschetti, F., 1998, Multiscale edge analysis of potential field data, Exploration Geophysics, 30, pp. 38-44.

Bierlein, F.P. and McKnight, S., 2005, Possible Intrusion-Related Gold Systems in the Western Lachlan Orogen, Southeast Australia. Economic Geology, 100, pp. 385-398

Burrowes, T., 2007. Exploration on the "Four Eagles JV" North Bendigo. VICMIN2007 Mineral Exploration Undercover, Australian Institute of Geoscientists Bulletin 45.

Christensen, A., Mahanta, A.M., Boggs, D.D.B., and Dransfield, M.H., 2001, Falcon airborne gravity gradiometer survey results over the Cannington Ag-Pb-Zn deposit, ASEG 15th Geophysical Conference and Exhibition, Brisbane, August 2001

Foster, D.A., Gray, D.R., Kwak, T.A.P., and Bucher, M., 1998, Chronology and tectonic framework of turbidite-hosted gold deposits in the Western Lachlan Fold Belt, Victoria: 40Ar-39Ar results. Ore Geology Reviews, 13, pp. 229-250

Fuller, T., and Hann, I., 2019, Updated NI 43-101 Technical Report Fosterville Gold Mine (2018), Kirkland Lake Gold, 244 p.

Miller, J.M., and Wilson C.J.L., 2002, The Magdala lode system, Stawell, south-eastern Australia: structural style and relationship to gold mineralization across the western Lachlan Fold Belt. Econ. Geol., 97, pp. 325-349

Miller, J.M., and Wilson C.J.L., 2004, Stress Controls on Intrusion-Related Gold Lodes: Wonga Gold Mine, Stawell, Western Lachlan Fold Belt, Southeastern Australia. Econ. Geol., 99, pp. 941-963.

Moore, D.H., 1996a, A Geological Interpretation of the geophysical Data for the Horsham 1:250 000 Map Sheet Area. Victorian Initiative for Minerals and Petroleum (VIMP), Report 24, Department of Agriculture, Energy and Minerals, 35 p.

Moore, D.H., 1996b, Geophysical Signatures of Gold Deposits in Western Victoria. In Hughes, M.J., Ho, S.E., and Hughes C.E., (eds.) Recent developments in Victorian geology and mineralisation. Australian Institute of Geoscientists Bulletin 20, pp. 43-48.

Moore, D.H., 1997, A geological interpretation of the geophysical data for the Ouyen 1:250 000 map sheet area. Victorian Initiative for Minerals and Petroleum (VIMP) Report 39, Department of Natural Resources and Environment, 47 p.

North Stawell Minerals 2021, Airborne gravity survey completed over North Stawell's tenure. ASX-Release, 08/06/2021,
Robinson, J.A., Wilson, C.J.L., and Rawling, T.J., 2006, Influence of volcano-sedimentary facies architecture on strain partitioning during the evolution of an orogenic-gold lode system, Stawell, western Victoria. Australian J. of Earth Sciences, 53, pp. 721-732.

Watchorn, R.B., Wilson, C.J.L., 1989, Structural Setting of the Gold Mineralization at Stawell, Victoria, Australia. In Keays, R.R., Ramsay, W. R. H., I. Groves, D.I., (eds.) The Geology of Gold Deposits: The Perspective in 1988, Economic Geology Monograph Series, Society of Economic Geologists.