Geophysical exploration and discovery at Jervois

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Introduction

The Jervois Project lies 250 km northeast of Alice Springs in the Northern Territory and is owned 100% by KGL Resources Limited (KGL). Access is via the Plenty Highway that passes within 15 km of the project, and then by the Lucy Creek Station Road.

Jervois is the largest base metal deposit in the eastern Arunta Region and comprises over ten prospects with mineral resources of varying size and grade. In July 2015, KGL announced a Mineral Resource of 30.5 Mt containing 327 000 t of copper, 22.6 Moz of silver and a growing inventory of lead and zinc that KGL has increased by 59% to 190 000 t since the 2014 estimate. A prefeasibility study was completed in December 2015 based on a 2.2 Mtpa flotation plant producing copper and lead-zinc concentrate to be transported by road and rail to the port of Darwin.

Increasing both size and the grade of the Jervois resource has been the primary objective of the exploration team; these efforts continue at Jervois on our known deposits and on prospects peripheral to the established resources. Various geophysical techniques in exploration targeting and resource extension have played a crucial role in achieving this success.

Base metal deposits give good geophysical responses and most methods have been employed at Jervois over the past 50 years, including:

- airborne magnetics, radiometrics and electro-magnetics (AEM) at ever decreasing line spacing and flying height
- ground magnetics and the sub-audio magnetic (SAM) derived total field magnetometric resistivity (TFMMR), total field electromagnetics (TFEM), total field induced polarisation (TFIP)
- ground electromagnetics - fixed loop (FLEM) and moving loop (MLEM);
- down hole geophysics including electromagnetics (DHEM), magnetometric resistivity (DHMMR)
- magnetic susceptibility and specific gravity (SG) measurements from chips and core
- multiple IP arrays including only the second Orion 3DIP survey completed in Australia
- magneto tellurics (MT)
- regional gravity (2 km x 2 km) and the most recent 100 m x 50 m microgravity survey.

Each of these geophysical surveys has added something to the geological understanding of the project area, although many of the earlier surveys have been repeated using modern, high resolution acquisition systems. Some have been instrumental in making new discoveries, others methods have helped unravel the structural and stratigraphic history, while at the same time creating conundrums for those geoscientists who enjoy trying to solve what is a very complicated puzzle.

Geology

Jervois is hosted by the Bonya Metamorphic Complex (Reno *et al* 2015) that forms part of the Aileron Province: a sequence of Palaeoproterozoic sedimentary rocks in the Arunta Region that formed part of the North Australian Craton prior to 1700 Ma (Scrimgeour 2013). Metasedimentary successions in the Aileron Province were deposited within the interval 1860–1740 Ma, and the majority of the magmatism occurred in the interval 1820–1700 Ma (Scrimgeour 2013). The Bonya Metamorphic Complex is a high-temperature, low-pressure package of metasedimentary rocks with protoliths interpreted to be equivalent to the lower Strangways Metamorphic Complex (Reno *et al* 2015).

At Jervois, the Bonya Metamorphic Complex is dominated by quartz-muscovite schist derived from metamorphosed siltstone and mudstone (**Figure 1**). The schist is interbedded with fine to medium grained beds of meta-sandstone that typically vary in thickness from 1 cm to 30 cm but thicker beds and lenses of meta-sandstone have been mapped at the surface. Within the fine grained schistose beds, there are broad belts with distinctive cordierite and/or andalusite porphyroblasts that give the rock a knotted appearance. Beds of marble and calc-silicate rock occur throughout the Jervois project area, but have poor strike continuity due to attenuated and boudinage during deformation. Although minor in extent, narrow beds of finely bedded quartz-tourmaline and fine to coarse grained volcanic/volcaniclastic rocks of rhyolitic composition have been mapped. The Jervois sequence is intruded by several phases of pegmatite and an amphibolite rock interpreted to correlate with the Attutra Metagabbro (ca 1786 Ma). The Bonya Metamorphic Complex is unconformably overlain by Neoproterozoic sediments of the Georgina Basin that forms a prominent ridge on the western edge of the project area.

Geophysical responses of Jervois mineralisation

Base metal mineralisation at Jervois is comprised of steeply dipping lenses of copper-silver and lead-zinc-silver sulfide that are stratabound within a 14 km trend along the ‘J-shaped’ range. The main deposits are *Marshall-Reward* and *Bellbird*, both copper-silver rich and hosted by quartzite and pelitic schist. *Green Parrot* and *Bellbird North* are smaller lead-zinc rich deposits hosted by carbonate and calc-silicate rocks. Between Marshall-Reward and Bellbird, there are several smaller satellite resources and prospects including *Cox’s Find* (copper), *Rockface* (copper), *Rockhole* (copper) and *Killeen* (zinc). The largest deposit, Marshall-Reward, is over 1 km long and up to 40 m wide, and has been drilled to a vertical depth of 800 m.

Most lithologies within the project area are highly electrically resistive providing good conductivity contrast to

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sulfide mineralisation. However, the high resistance creates issues of high contact resistance for electrical surveys that require fast current turn-off times for EM surveys in order to record shallow conductivity anomalies.

The task of designing surveys that will optimally couple with, or accentuate the responses from mineralisation is assisted by the predictable strike and dip of bedding within the Jervois syncline. Modeling the measured responses is easier due to the stratabound nature of the mineralisation constraining the possible orientation of the anomalous response, resulting in a more accurate model and hence more accurate targeting of the response.

The steeply dipping orientation of the sedimentary package also enables shallow penetrating systems such as SAM and the higher frequency components of a ground magnetics system to register subtle differentiation between and within the lithologies.

There are only minor thicknesses (typically 1–2 m) of regolith of transported cover and completely oxidised material at Jervois. This is an advantage for electrical methods where the current might otherwise channel within the conductive clays in the upper-part of the regolith profile. In the absence of a conductive regolith, the electrical currents can penetrate deeper and interact with the sulfide bearing minerals.

The depth of the transition zone is variable, ranging from a few metres to tens of metres. It is typically deeper over areas of high sulfide content and where there is significant shearing and faulting. The upper transitional zone is leached with corresponding supergene enrichment of copper in the lower transition zone. Chalcopyrite has been altered to bornite and chalcocite with rare native copper, all of which are conductive. Assaying of acid soluble copper within the transition zone has demonstrated that the sulfide content is typically around 50-55%. Consequently, even within the transition zone, a reasonably good IP chargeability response can be expected.

In the copper-rich lenses, chalcopyrite is the main copper sulfide mineral, often associated with minor pyrite. Chalcopyrite can be disseminated, veined, semi-massive and massive over intervals of up to one metre. When disseminated, the sulfide can follow bedding planes that coincide with the pervasive D^2 foliation. Remobilisation of the chalcopyrite into low pressure zones along fractures,

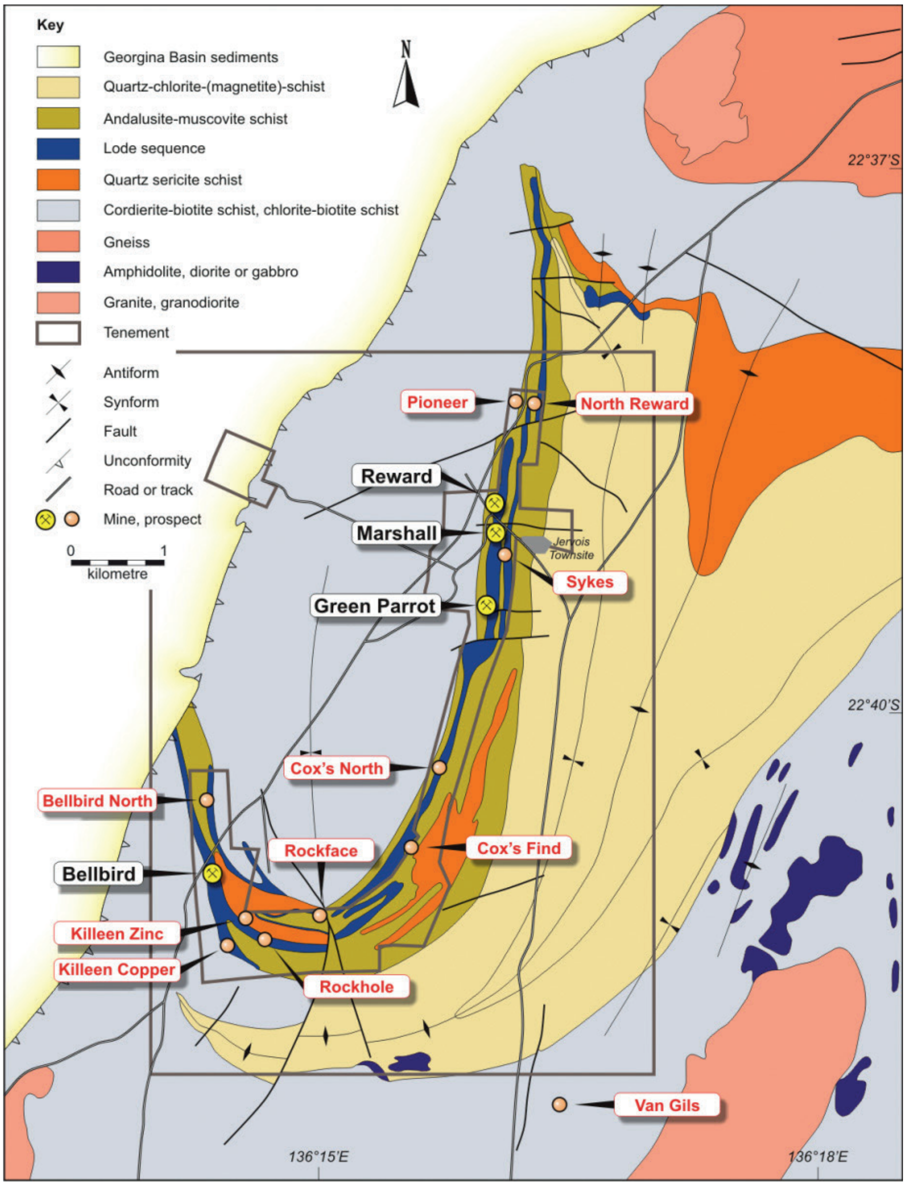

Figure 1. Jervois geological map.

crenulations and folds is evident at various scales. Sulfide mineralisation is more commonly disseminated than massive or semi-massive thus IP chargeability has been very effective at delineating areas of interest; however, the IP response can be difficult to differentiate between low and medium grade mineralisation even with the aid of the associated resistivity measurements.

In 2000, MIM Exploration Pty Ltd conducted a large MIMDAS dipole-dipole IP survey (MIM Exploration's proprietary 'distributed acquisition system') that included the Bellbird region, extending east to the Rockface Prospect. The Bellbird deposit produced a coincident chargeability/conductivity anomaly; smaller point source anomalies were modelled at Rockface. A recent 3D inversion of historical IP data significantly improved the results. However, many anomalies remained poorly defined due to the survey configuration and the changing strike of bedding that makes targeting difficult. In 2015, KGL resurveyed the Bellbird area using the Orion 3DIP system which generates a 3D point cloud of data without the directional bias of the earlier IP surveys. Strong chargeability anomalies were again identified at Bellbird. In addition, a strong coincident chargeability/conductivity anomaly was modelled below the small Rockface resource (**Figure 2a, 2b**). Subsequent drilling of the Rockface anomaly intersected high-grade copper mineralisation in a massive magnetite-chalcopyrite rock. A hybrid array was designed and used for this survey, the first of its kind for the Orion 3DIP system, significantly reducing both the time and ultimately the cost of the survey. Further research is now being conducted by Quantec Geoscience with the benefit of the Jervois data to investigate the potential to further reduce acquisition time with modified arrays and dipoles.

The 3DIP survey was run during the day and in the evenings, a network of receivers were laid out to record both high and low frequency MT. This MT data were acquired to help map the resistivity beyond the limited depth of investigation for the 3DIP survey (**Figure 3a**, **3b**). This data resolved two significant conductors, the first coincident with the Bellbird deposit and likely reflecting a down dip extension; the second in the Chubko area that was completely unexpected. The exploration potential of this Chubko anomaly will be assessed further after the gravity survey has been completed.

In 2011, Jinka Minerals conducted a SAM survey at 40 m line spacing over the mine sequence at Jervois, acquiring both ground TMI and TFMMR data. The TFMMR data, which relies on current channeling, proved very useful in differentiating between mineralised and unmineralised lithologies where the absolute difference in resistivity is small (**Figure 4a**). These types of targets are not easily detected using time doman EM systems. The SAM system employs a 50% duty cycle and the receiver records into the off cycle measuring a decaying response. Analysis of these data showed large coherent anomalies over both of the main deposits and many smaller anomalies that require field checking (**Figure 4b**). Initially this was thought to be an EM response but now now is considered more likely to be an IP response. A research program has commenced with Gap Geophysics Australia and University of British Columbia to see what additional information can be gained from this data.

Downhole EM has also been used extensively at Marshall-Reward where higher grade copper mineralisation (>1.5% Cu) has generated moderate to good conductivity responses. Grades lower than 1.5% typically give no conductivity response or, at best, a very weak response. There are no graphitic units or any significant conductors other than sulfide mineralisation and a good response is typically caused by high-grade copper or lead mineralisation. DHEM in hole RJ237 identified a large conductor below the existing Reward deposit that has yet to be tested. After the good intersection at Rockface in hole KJCD171 (13 m at 2.14% Cu, 12.5g/t Ag, 0.10g/t Au from 255 m and 2 m at 2.83% Cu, 10.8g/t Ag, 0.05g/t Au from 278 m), a DHEM survey was conducted and identified two strong conductors extending down dip to 300 m below the existing resource (**Figure 5**).

Fixed loop EM data was acquired at the Marshall-Reward resource by KGL in 2014. Weak anomalies coincide with the known lodes at Reward and Green Parrot although the anomalies are discontinuous with the breaks likely caused by zones of lower grade mineralisation.

Proximal alteration assemblages at Marshall-Reward and Bellbird commonly include magnetite and garnet. End members of the proximal alteration assemblage are garnetite and massive magnetite-ironstone. The biotite-chlorite-magnetite-garnet alteration gradually diminishes with increasing distance from the sulfide lenses but can extend for up to 50 m.

Magnetite alteration is associated with a strong, 2 km-wide magnetic response in total magnetic intensity (TMI) images that defines the shape of the J-Fold (**Figure 6**). Mineralised trends within the Jervois Range have well defined linear magnetic anomalies in TMI 1VD images. At Marshall-Reward, the anomaly is 50 m wide and 2.1 km long with the ends terminating against faults. Although Marshall-Reward has a good magnetic response, not all linear magnetic anomalies are caused by mineralisation. The association with magnetite has meant that magnetic surveys at a prospect scale have been useful in identifying extensions to mineralisation; in the case of Rocky Road, the surveys have provided additional targets within the prospective stratigraphy.

Magnetite and garnet-altered rocks proximal to mineralisation are significantly denser than the unaltered country rocks and constitute a good gravity target. Addition of high density sulfide minerals makes the gravity response potentially larger. Mineralisation recently intercepted at Rockface comprised massive magnetite-chalcopyrite mineralisation (KJCD171) with an average specific gravity (SG) of 4.3. This compares with a typical SG of 3.1 for the more disseminated Bellbird mineralisation and 2.9 for adjacent metasedimentary rocks. High-grade copper mineralisation intercepted at Reward in RJ169 (72 m at 3.3% Cu, 51.2 g/t Ag, 1.16 g/t Au from 414 m) had an average SG of 3.4.

The lead-zinc rich lenses are hosted by carbonate rocks that have been altered to calc-silicate and a skarnoid assemblage. Sphalerite and galena are the dominant sulfides that range from disseminated to high-grade massive lodes.

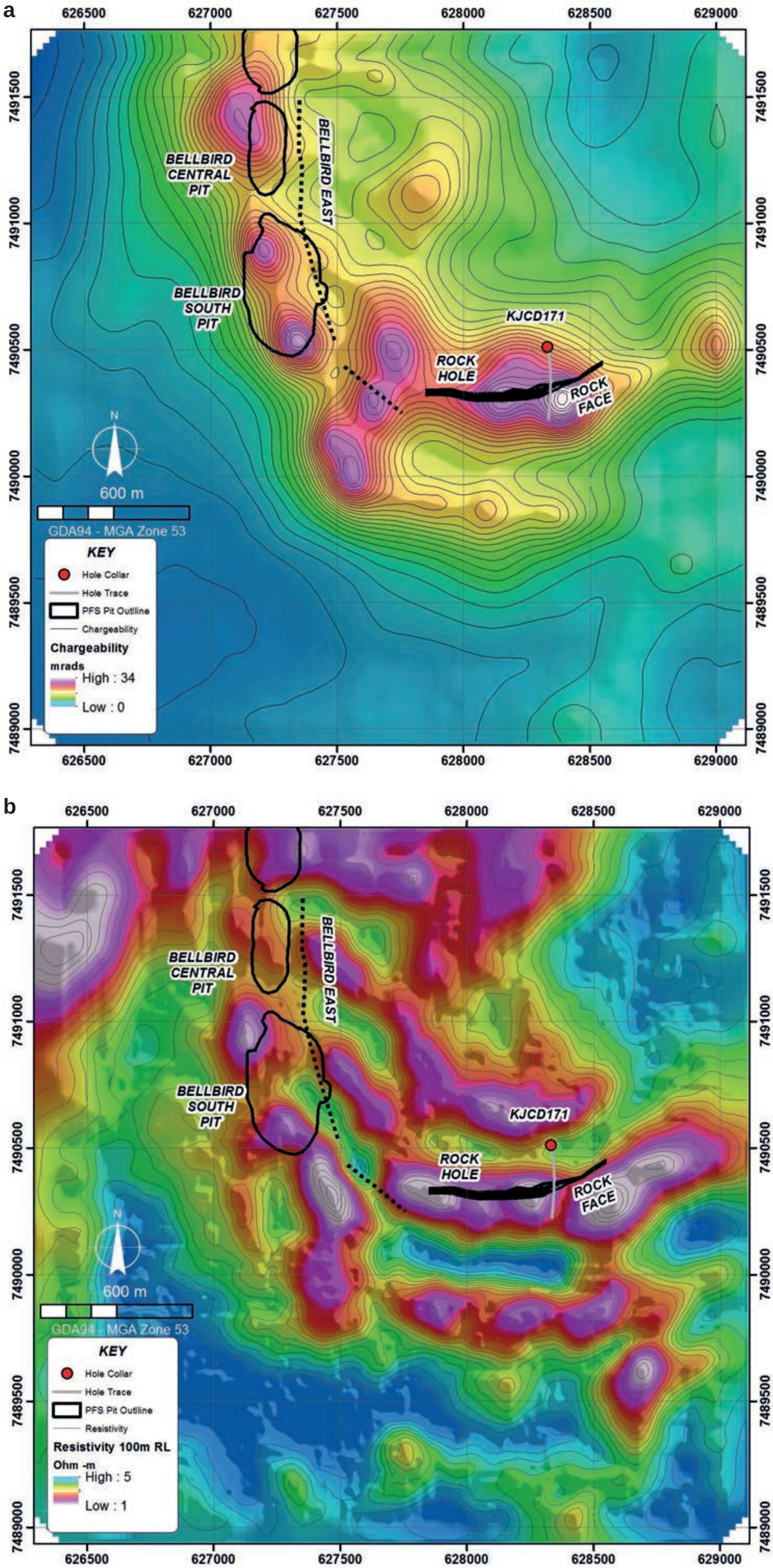

Figure 2. (**a**) Orion 3D-IP Chargeability 100 mRL depth slice. (**b**) Orion 3D-IP Resistivity 100 mRL depth slice.

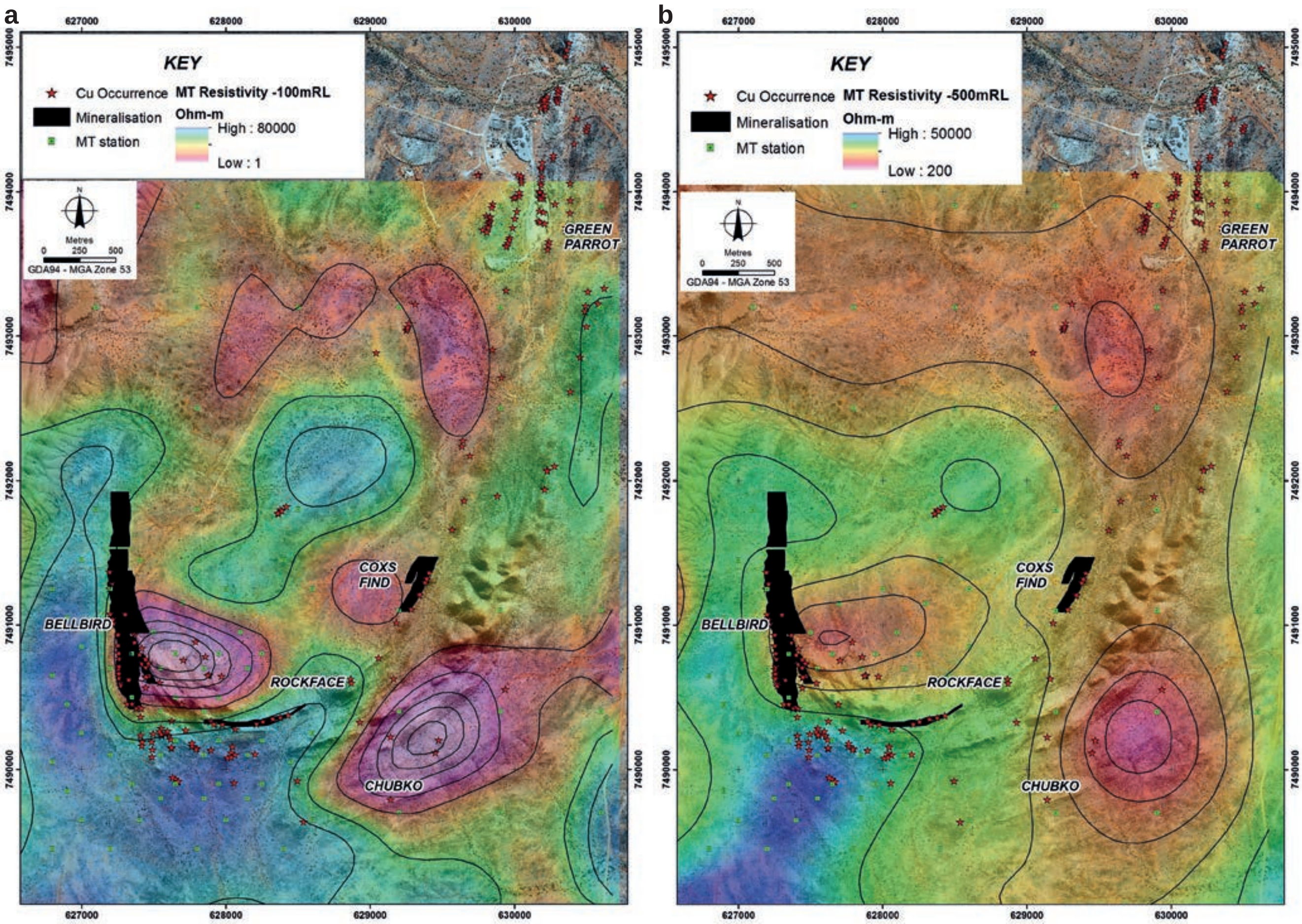

Figure 3. (**a**) Magneto Telluric Resistivity -100 mRL depth slice. (**b**) Magneto Telluric Resistivity -500 mRL depth slice.

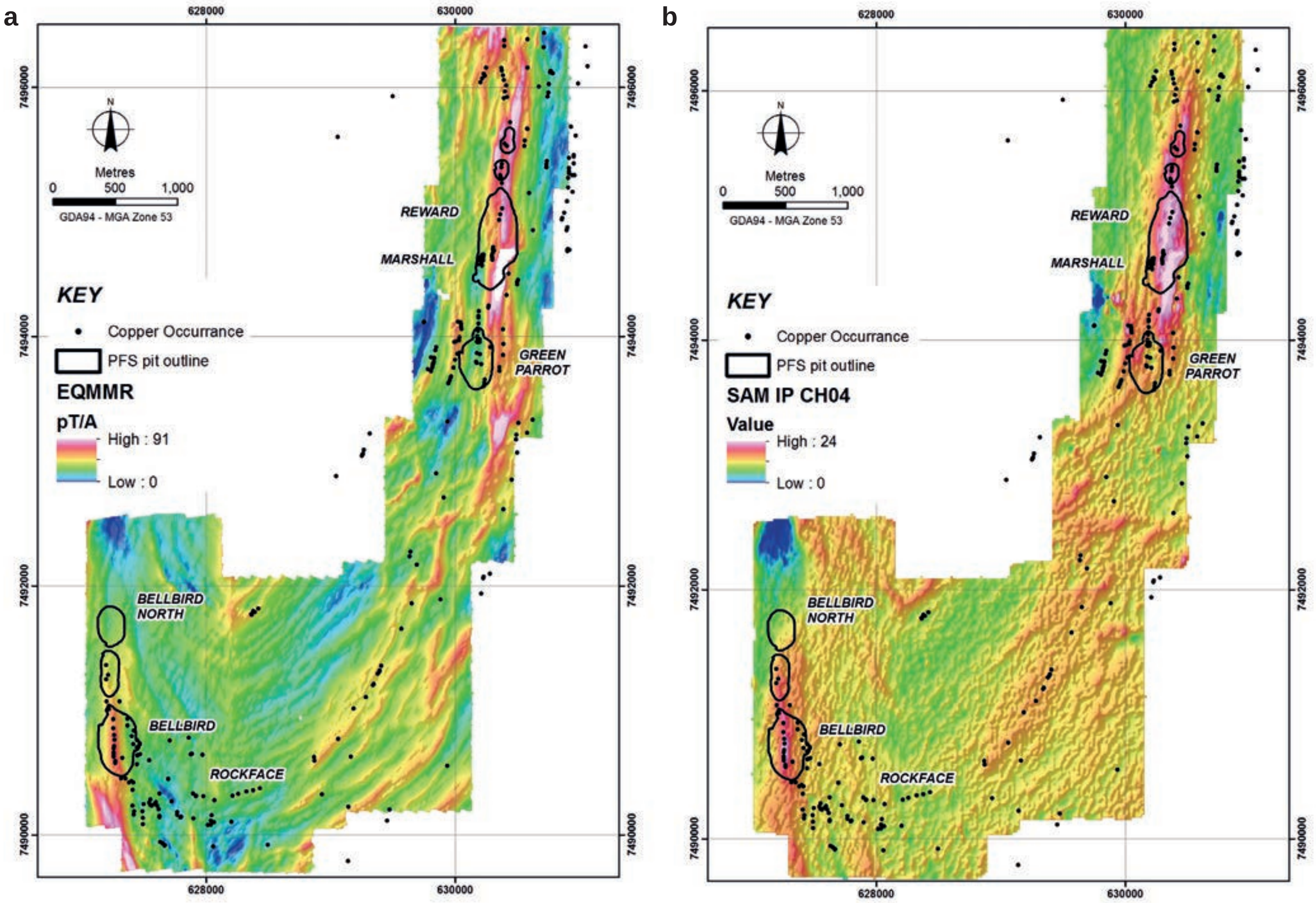

Figure 4. (**a**) SAM TFMMR. (**b**) SAM TFMMIP.

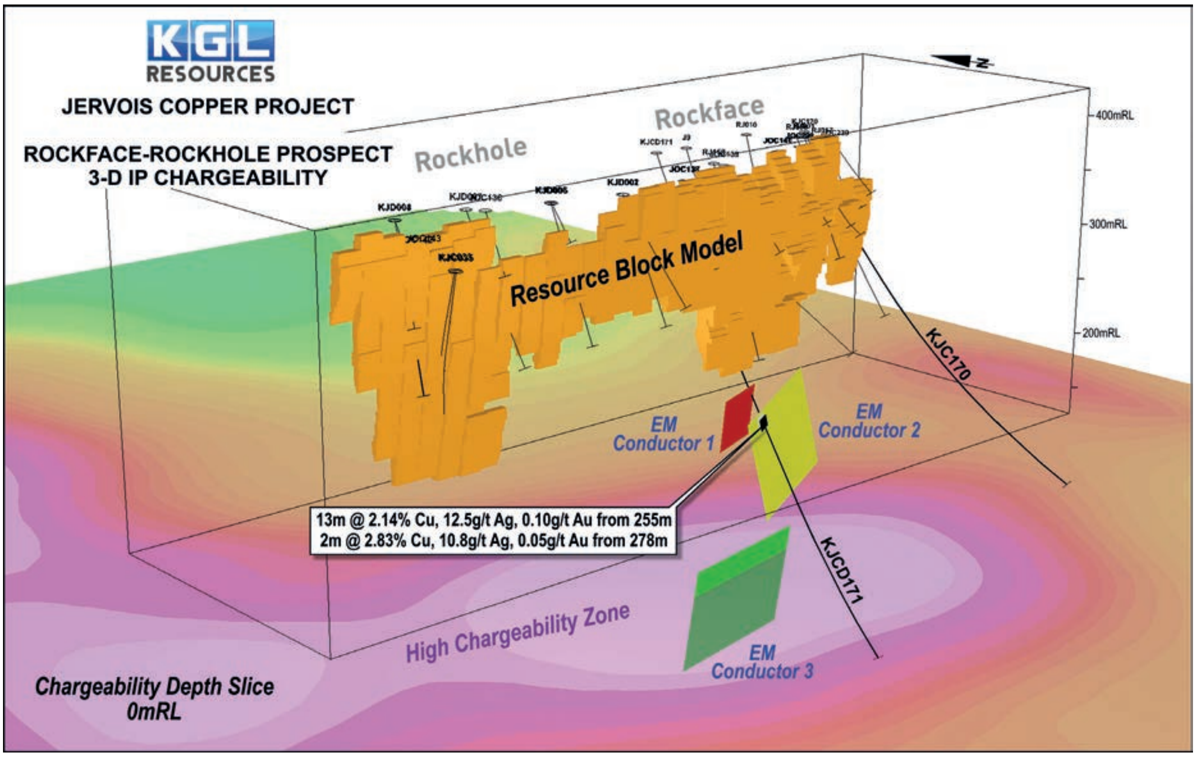

Figure 5. Rockface DHEM modelled conductive plates.

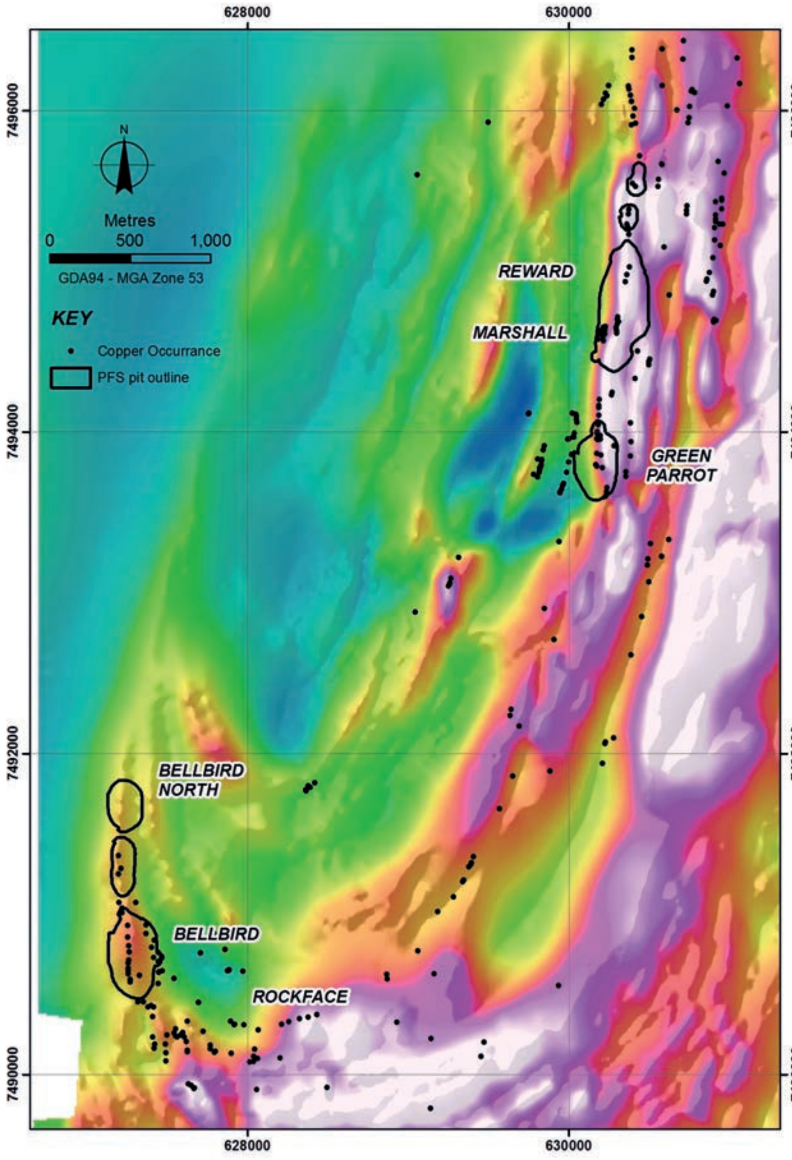

Figure 6. TMI 1VD of airborne magnetics.

Chalcopyrite can occur with sphalerite and galena, but in most cases it has a low ratio by volume. Accessory sulfides are varied with pyrite, pyrrhotite, covellite, tennantite, molybdenite and bournantite recorded.

Green Parrot was the first calc-silicate hosted lead-zinc deposit to be discovered and subsequently mined briefly, by Plenty River Mining in 1982, with Bellbird North discovered later by step out drilling north of Bellbird. At Bellbird North, zinc dominates rather than lead unlike that at Green Parrot. The copper and lead-zinc rich resources were initially considered to be spatially separated until 2013 when a high-grade lens of lead-zinc mineralisation was discovered in the footwall of Marshall-Reward, only a few metres from the copper resource (KJCD048 18 m @ 0.88% Cu, 19.63% Pb, 3.77% Zn, 732.3g/t Ag, 0.61g/t Au from 287 m and 57 m @ 0.51% Cu, 0.46% Pb, 1.62% Zn, 42.7g/t Ag from 230 m). Airborne EM data acquired over Jervois by Poseidon Exploration Limited in 1991 identified a short strike length conductor at Reward that was initially interpreted to be caused by mine infrastructure because the rest of the Reward resource was not conductive. It was only in 2013 when a lens of massive lead-zinc sulfide was discovered at depth in KJCD048 that the actual source of the conductor was correctly interpreted.

Future exploration

There remains much to be done to fully integrate all of the geophysical, geological and geochemical information that has been acquired at Jervois. This process has started with the revised bedrock geology plan and 3D geological model, both important initiatives. The recently completed gravity survey may cause us to re-evaluate or possibly confirm some of our assumptions. It also has the potential to highlight new targets or reprioritise existing targets. As a geoscientist, it is always exciting to have new data in any form as ultimately we want to know that we have identified all the existing economic mineralisation. However, it is always worthwhile revisiting historic datasets with the benefit of new knowledge to test previous interpretations.

The drilling program that commenced in February 2016 has a number of objectives, including:

- upgrading shallower mineralisation at Green Parrot
- testing the DHEM conductors at Rockface
- testing the magnetic anomaly at Rocky Road
- testing numerous soil and RAB anomalies, many of which were initially targeted with the help of geophysics, particularly in the areas of transported and younger cover.

The application of geophysical methods has and will continue to play a crucial role in the exploration, discovery and delineation of mineral deposits at Jervois as the project is progressed towards its full potential to be developed into a major polymetallic mine.

Acknowledgements

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